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October 2022

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Prof. Dr. Z. Ozlem PARLAK BICER
Doç Dr. F. Yeşim GÜRANİ

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CHAPTER 1

BUILDING DESIGN PARAMETERS FOR HOT-DRY CLIMATIC ZONES

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INTRODUCTION

Buildings must provide users to live in a physically, mentally and climatologically comfortable built environment with the necessary conditions. The similarity of the necessary conditions for providing comfort in hot-dry climatic conditions, which can be seen in different parts of the world, results in similar architectural design features. The requirements for buildings in hot-dry climatic zones are to reduce the rise in indoor air temperature during summer days, keep the indoor air temperature and thermal mass of the building cool during summer nights, and keep the ambient temperature within the comfort temperature value. While passive air-conditioning and heating systems meet these requirements, they also form the building design parameters for hot-dry climatic zones and provide energy conservation.

1.DESING PARAMETERS RELATED TO USERS

Humans, like other things, exchange heat with their environment through direct contact, convection, radiation (mainly short and long wavelengths rays), and evaporation/condensation (heat release as a result of phase change). Heat balance arises from the interaction of environmental factors such as indoor air temperature, average radiant temperature, humidity, and air movement, as well as user-related parameters such as metabolic rate and clothing.

Humans are affected by climatic comfort conditions in terms of physical and mental performance; hence, individual factors such as activity status and clothing type should be appropriate for the environment. For example; individual activities such as sleeping, sitting, walking and jogging have different metabolic levels. Therefore, depending on the metabolic level, the level of heat energy that the body produces and transfers to the environment during different activities also differs. In Table 1.1, the average metabolic level of an adult individual according to the type of activity and the energy produced in metabolic equivalent minute (MET) units are given (1 met=58.2 W/m^2).

Table 1.1: Metabolic levels of different activities (Rosenlund, 2000).

Type of Activity	Met	Metabolic Level
Sleeping	0.7	75
Resting lying down	0.8	85
Sitting	1	105
Standing	1.2	125
Cooking	1.6-2.0	170-210
House Cleaning	2.0-3.4	210-350
Walking (by 3-6 km/h)	2.0-3.8	210-400

Dancing, Exercising	2.4-4.4	250-460
Heavy Machinery Work	3.5-4.5	370-470
Digging and Shoveling	4.0-4.8	420-500

Due to the high temperature felt in hot-dry climatic zones, the human body heats up more and releases more energy as a result of its movements. The level of climatic comfort a person feels also differs according to the material and thermal resistance of the clothing they wear. Clothes with low thermal resistance should be preferred in hot-dry climates, and the temperature value between the human body and the environment should be kept in balance. In Table 1.2, the approximate thermal resistance values for various clothing types are given in Clo units (1 clo=0.155 m^2/W).

Table 1.2: The approximate Clo values for various clothes (Roselund, 2000).

Type of Clothing	Clo
Naked	0
Shorts	0.1
Shorts + Short-sleeved Shirt	0.4
Knee-high skirt + Short-sleeved shirt + Panty-hose	0.5
Pants + Shirt	0.6
Sweatpants + Sweatshirt	0.7
Pants + Shirt + Jacket	1.0
Knee-high skirt + Long-sleeved shirt + Panty-hose + long-sleeved sweater or jacket	1.0-1.1
Men's Suit (Thick)	1.5
Men's Suit (Thick)+ Wool Overcoat	2.0-2.5

DESIGN PARAMETERS RELATED TO EXTERNAL ENVIRONMENT

The climate of a region is defined by an analysis of the observed changes in the weather condition of that region over a period of time. Parameters related to external environment vary according to the geographical and topographical features of the region, resulting in the formation of different climatic zones. Due to the harsh climatic conditions of hot-dry climatic zones, evaluation of climatic parameters in the design process is critical. Exterior temperature, solar radiation, wind and humidity are examples of climatic parameters that generate design parameters related to the external environment.

1.1. Exterior Temperature

One of the basic characteristics of hot-dry climates is that temperature values differ daily and by season. Summer days in most of the arid regions, especially on lands and in mountains, are very hot and dry; on the other hand, summer nights are cool, if not cold. The temperature value can vary up to 15-20 °C during the day, and the minimum temperature value is usually below 15°C. While the weather is usually clear and sunny on winter days, the nights are cold and the temperature value is near or even below zero degrees (Meir and Roaf, 2002). Daily and seasonal temperature values that generate part of the characteristic features of hot-dry climatic zones largely affect the design of the structures in these areas.

1.2. Solar Radiation

Hot-dry climatic zones receive the sun rays more steeply and for a longer period of time due to their proximity to the equator and low latitudes. As a result, the intensity of solar radiation increases, causing temperatures in these areas to rise, particularly in the summer. In hot-dry climactic zones, the need for solar protection emerges in order to be protected from the negative effects that may be caused by high temperatures during the summer. Therefore, different systems that can be integrated into the building design should be developed, and solar radiation that causes overheating should be prevented from reaching the buildings. Solar radiation from the south should be acquired in a controlled manner during the winter months to obtain energy gain.

1.3. Wind

The direction and the intensity of the air currents are important factors in shaping the built environment. While air currents from the north have a cooling effect in the hot-dry climatic zones of the northern hemisphere, dry air currents from the south cause the temperature to rise. Natural ventilation methods should be used to cool the environment using wind in hot-dry climates, and to humidify the environment using water elements in windy areas, again using the wind. Thus, wind, which is sometimes regarded as a negative climate element, can be used as an effective parameter in developing climate-compatible buildings and improving comfort conditions.

1.4.Exterior Humidity

Humidity in hot-dry zones is low throughout the year, and in line with that, the amount of rainfall throughout the year is also low. Dry weather conditions and accompanying hot winds creates extremely uncomfortable conditions for settlements located in hot-dry climatic zones. That's why in the design phase of buildings to be built in the hot-dry climatic zones, for the seasons with high temperature; shady areas should be created to be protected from severe solar radiation, and while protection from dry winds is ensured, humid winds should be benefited from. And for the seasons with low temperatures, it is necessary to develop design strategies that will increase the efficiency of solar energy as a heat source.

2.DESIGN PARAMETERS RELATED TO BUILT ENVIRONMENT

Designing climate-compatible buildings is possible by analyzing the parameters related to external environment and developing design solutions for these parameters in the built environment. Some designing strategies to be applied in hot-dry climatic zones are effective in providing climatic comfort as well as energy preservation and efficiency, with settlement and building scale solutions for climatic parameters.

2.1. *Design Parameters in Settlement Scale*

2.1.1.Location of the Building

The appropriate location for the building is determined by adhering to the average annual temperature and humidity values of the region in which the land is located. In hot-dry climatic zones, it is necessary to locate in such a way that extreme effects of solar radiation and dry wind are avoided, except during the months when heating is required. Hence, level or nearly level topographies are the most economically and environmentally suitable areas for settlement in hot-dry climatic zones. Settlements on level areas keep the effects of gained solar radiation and potential negative solar radiation to a minimum. Building a structure in sloping topographies causes both ecological and economic issues due to factors such as increased land intervention and increased construction costs.

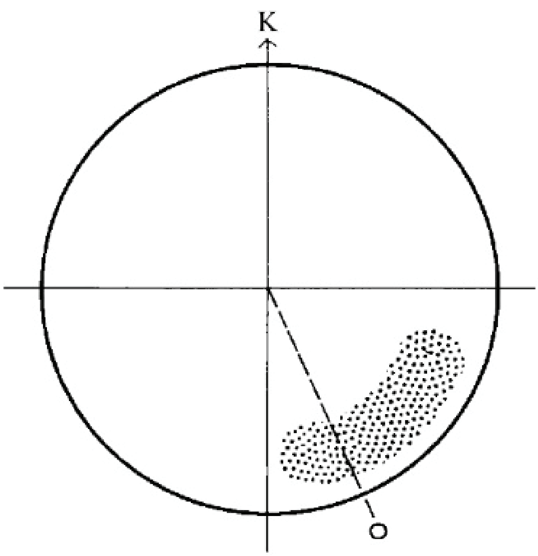

Figure 3.1: Optimum settlement location in hot-dry climatic zones according to Olgyay (Olgyay, 1963).

2.1.2.Building Spacing

Building spacing affects the solar radiation and wind exposure levels of building surfaces. The length of the shadows cast by buildings is one of the most important factors in determining building spacing and street texture based on the climate of the region. In hot-dry climate zones, the effect of solar radiation is desired to be minimized. Hence, the building spacing should be set to be less than the shortest shadow length cast by the buildings in the built environment. The narrow street texture and closely spaced structuring create shaded, heat-protected areas on the streets, allowing the building facades to receive less solar radiation (Figure 3.2). Air movements between buildings are also related to narrow street texture. In the summer, narrow streets that are shaped according to the prevailing wind accelerate air movements; on the other hand, dead-end-streets that open to the prevailing wind direction slow down wind and thus create cool environments.

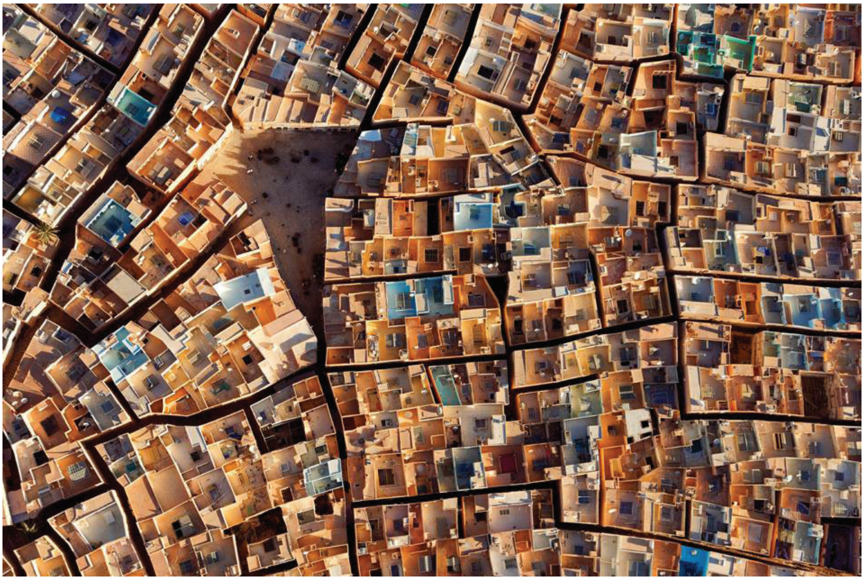

Figure 3.2: Narrow street texture and closely spaced structuring, Beni Isguen, Algeria (Url-1)

2.2. *Building Scale Design Parameters*

2.2.1.Building Orientation Status

Due to the harsh conditions of hot-dry climate, orientation status in these regions should be carefully handled in accordance with the characteristics of climatic parameters such as sun and wind. The intensity of solar radiation per unit area in the building envelope varies depending on the geographical direction of the building facades. As a result of the studies conducted in hot-dry climates, it is deemed appropriate that buildings be situated in the east-west axis and face south in order to minimize heat gains through conduction from the building envelope. V. Olgyay describes the direction from south to 25° east as optimum in these regions, and the direction from south to 35° as good (Figure 3.3). In some cases, appropriate building orientation status may not be provided due to factors such as topography status of the area where the design will be applied, zoning status, and so on. In such cases, building designs should include shading elements, and heat gain from solar radiation should be minimized.

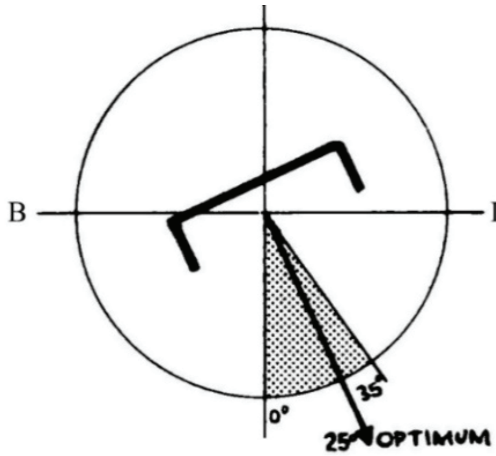

Figure 3.3: Optimum building orientation in hot-dry climatic zone according to Olgyay (Olgyay, 1963).

2.2.2.Building Form

The shape of a building has a significant impact on the heat gain or loss caused by solar radiation. Geometrical characteristics of a building such as the height, the type of roof (flat, saddle, hipped) and roof slope, as well as the slope and shape of the facade, define the building form as a whole and form the building's outer surface area. The ratio of exterior surface area to volume (A/V) of a building has a direct impact on the heat gain and loss caused by solar radiation. Hence, in hot-dry climatic zones where the increase in temperature throughout the summer days is desired to be kept at a minimum, buildings should be designed in a compact form with as little exterior surface area as possible. The appropriate building form and form factor (the ratio of building height to depth) to achieve the desired heat loss and gain are shown in Figure 3.4.

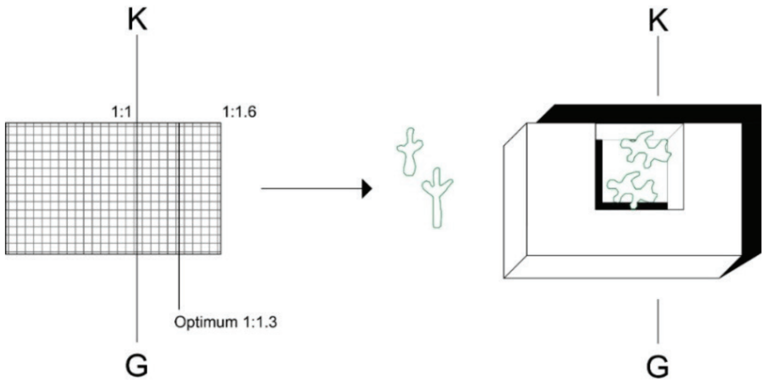

Figure 3.4: The appropriate building form and form factor value for hot-dry climatic zones according to Olgyay (Olgyay, 1963).

In hot-dry climatic zones, courts play an important role in architectural design. Courts, which provide shade throughout the day, become a part of daily life in these areas. The court allows the heated air that accumulated in the building during the day to be discharged, and the cool air is let into the building at night, depending on the high temperature difference between the day and night in hot-dry climate regions.

Different architectural elements can emerge in settlements with the same hot-dry climate, but located in different regions. For instance, in traditional Diyarbakır houses, different court plans are seen, and around the court, there are summer, winter, and spring sections according to the seasons. In these houses, summer section faces north, winter section faces south, and spring sections face east and west (Figure 3.5).

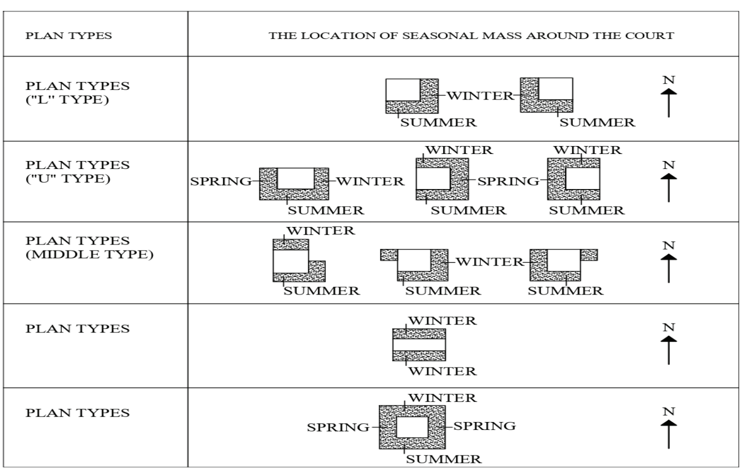

Figure 3.5: Plan types of old Diyarbakır houses and different orientation locations (Akın, 2001).

2.2.3.Building Envelope

Building envelopes have thermal properties such as thermal conductivity, heat retention capacity, as well as exterior properties such as color, texture, and radiance. These properties of building envelopes affect the building envelope performance and climatic comfort. In comparison to opaque surfaces, the thermal conductivity coefficient of transparent surfaces in the building envelope is quite high. Because the heat gain is desired to be minimized in hot-dry climate regions, transparent surface areas such as windows should be kept as small as possible or with well-isolated shutters and blinds in summer, protection from the heat of solar radiation should be provided during daytime. Due to the high temperature differences between day and night, materials that store and preserve heat throughout the day and delay the high temperature reaching the interior spaces should be used on the walls. Therefore, in hot-dry climate regions, adobe brick, natural stones, and soil are commonly used as building materials. The use of local materials has become important economically and ecologically because they are easily accessible and climate-compatible.

Walls, which act as a thermal mass, stores the heat from the solar energy during the day, and circulate it indoors at night when the temperatures drops. Some of the solutions in traditional and/or local architecture developed according to the conditions of the time it was built and the climate of the region shape today's climate-compatible architecture. Some of the old methods can be developed with the help of modern technology and can be adapted to contemporary architecture.

For example; "The Revolving Bricks Serai" located in Arak, Iran, which has a hot-dry climate, combines the traditional/local architecture with contemporary structure with its double façade made of glass and brick and the brick-surfaced perimeter with a parametric form (Figure 3.6). While the brick surface in the outer layer of the facade attributes to traditional/local architecture, the high thermal capacity of the brick material and the air void between the facade and the building ensures passive cooling and ventilation of the living spaces. The double-façade wall setup of the building provides appropriate use of light and sound insulation, as well as heat control (Figure 3.7).

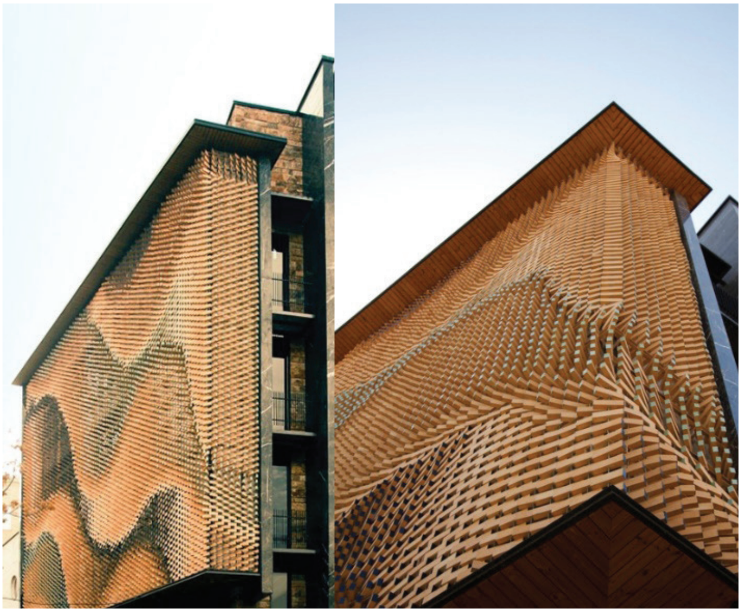

Figure 3.6: The Revolving Brick Serai (Url-2).

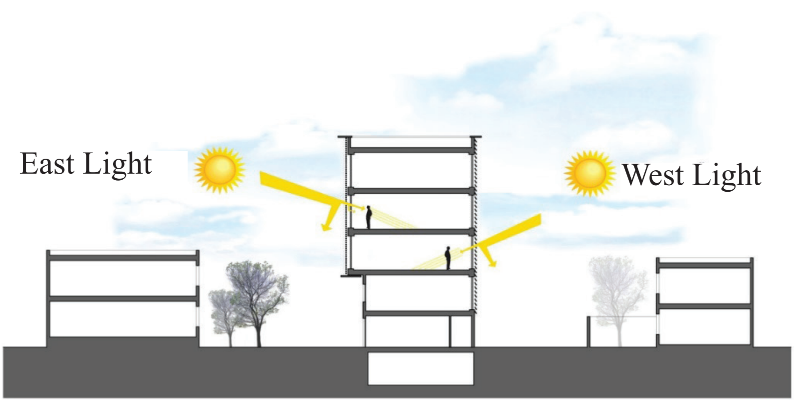

Figure 3.7: The Diagram of solar radiation of Revolving Brick Serai (Url-2)

2.2.4.Natural Ventilation

The pressure differences between the outdoor and indoor environments cause the formation of natural air currents due to the high pressure surrounding cold air and the low pressure surrounding hot air. The position and dimensions of different ventilation gaps on the facades affect the characteristics of the air current, such as their speed and direction, depending on the external weather conditions. The fact that high temperature value in hot-dry climatic zones and high temperature differences between day and night make natural ventilation an important architectural design element so that people can feel comfortable physiologically and psychologically. High-positioned ventilation gaps keep hot air pockets from forming beneath the ceiling (Figure 3.8). As in Harran cupola houses, few and small windows and ventilation gaps provide protection from the effects of negative solar radiation (Figure 3.9). A ventilation gap at the apex, which is a low-pressure region, is effective in removing hot air from areas covered with a cupola or vault (Figure 3.10).

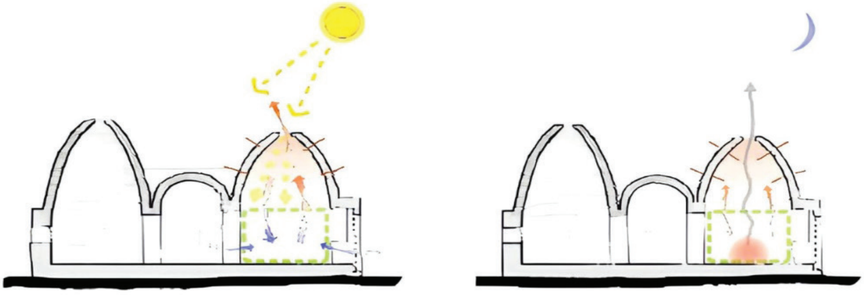

Figure 3.8: Cupola house section (Url-3).

Figure 3.9: Cupola houses, Harran, Şanlıurfa (Url-4).

Figure 3.10: Inside the cupola houses, Harran, Şanlıurfa (Url-5).

Wind towers are used in Iranian houses to provide natural ventilation. The fresh air from outside enters the wind tower called “badgir” and is directed to the water reservoir called “qanat” under the house with the air current, taking advantage of pressure differences caused by temperature differences (Figure 3.11). In qanat, cool air circulates around the house, keeping the building cool, while hot air is vented out through wind towers (Figure 3.12).

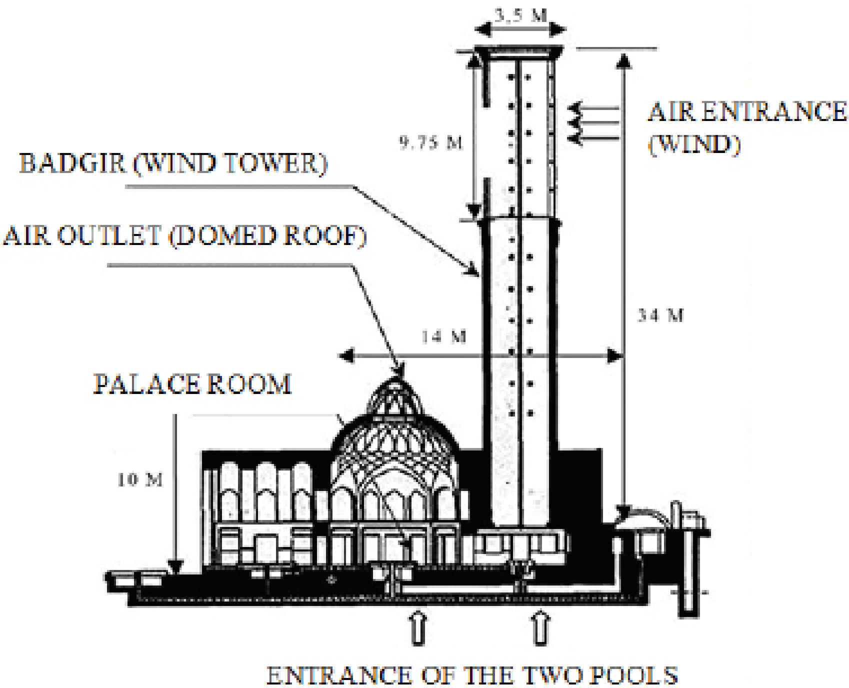

Figure 3.11: Wind tower in Dolat-Abad Garden, Yezd, Iran (Habibzadeh, 2018).

Figure 3.12: Wind tower in Dolat-Abad Garden, Yezd, Iran (Url-6).

2.2.5.Solar Control

In hot-dry climatic zones, when the amount of solar radiation affecting the buildings cannot be controlled, problems such as overheating and glare create uncomfortable spaces for the users. In situations where solar control is ineffective, solar radiation with high temperatures entails resorting the use of fossil-fuel cooling systems, thereby increasing carbon emissions. Solar control can be provided with landscape elements placed near buildings during the summer, when the sun rays are more intense (Figure 3.13). Apart from natural shading tools, cantalevers, and eaves designed on building surfaces, as well as indentations around the windows, are used as shading elements to limits overheating and the negative effects caused by overheating, and to control glare. The use of shading tools is especially important on south facades, and the amount of transparent surface area on the south and west facades should be reduced. High performance window systems should be used when transparent surfaces are required and the need for shading tools should be minimized.

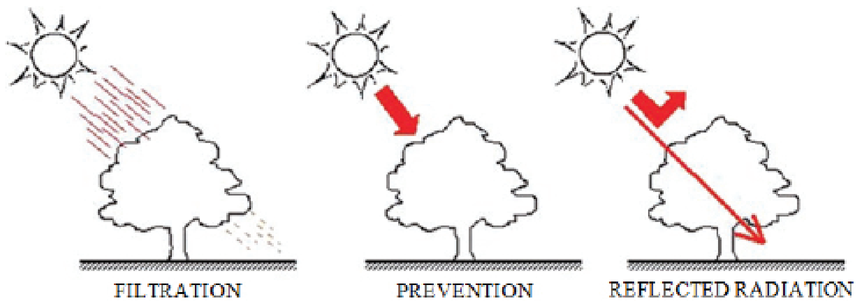

Figure 3.13: Solar radiation control (Guedes and Cantuaria, 2019).

3.CONCLUSION

The fact that hot-dry climate will be seen globally in the coming years necessitates a thorough analysis and comprehension of these climate characteristics. It is critical that building designs are compatible with climate, since the majority of the energy consumption is used to provide comfort conditions. Certain design decisions should be made regarding the location of the settlement and building scale in order to avoid uncomfortable spaces related to climate and to balance negative climate conditions that may emerge in hot-dry climatic zones. When making design decisions, energy efficiency can be achieved with the materials used in traditional/ local settlements and some passive air-conditioning systems can be adapted to modern-day structures, as well as with contemporary buildings built using developing technologies and construction systems. Hot-dry climate requires protection from adverse climatic effects such as high-temperature solar radiation and strong dry winds in regions where this climate type is observed. On level or nearly level lands, closely-situated structures reflect the appropriate settlement type; and the building envelope with a high heat retention capacity, on the east-west axis, oriented from south to 25° east, with a court and a compact form reflects the appropriate structural features for this climate type. It is important to incorporate natural ventilation and solar control into various different design decisions in order to allow cool air into the structure, remove hot air from the structure, and keep the temperature from rising to undesirable levels.

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CHAPTER 2

FACADE AND ADAPTIVE ARCHITECTURE

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INTRODUCTION

The facade is commonly considered to be the face of a building. In the architectural dictionary, it is defined as "each of the visible surfaces of a building, especially the front face or the view from infinity in the direction perpendicular to the building face" (Hasol, 2009). Although most people consider it just a decorative element, it is only a feature of the facade. In simple terms, the facade of a building shows one side of the building, especially the entrance, and plays a role in distinguishing it from other structures in the surrounding area.

Facades usually do not carry a load other than their own load. Their main task is not to try to keep the building standing, but rather to support the structure. They are most valued for their visual appeal, but they also determine the performance of the building. Facade elements provide vertical and lateral resistance to wind, sunlight and other environmental influences. At the same time, it plays a major role in the development of issues such as weather resistance and thermal effect, safety, acoustics, fire resistance in facade structures.

The components they contain and their functions should be examined together. There are main tasks that facades are expected to meet basic needs. These tasks (Schittich, 2006) and other features can be listed as follows:

-Ventilation,

-Lighting,

-Providing insulation against humidity and hot/cold weather conditions (protection against wind, protection against sun),

-Protection against glare,

-Visual protection (privacy)

-Establishing a visual relationship with the outdoors

-Security, creating a boundary between the public space and the interior

-Providing mechanical strength,

-Providing sound insulation,

-Protection against fire,

-Ensuring energy efficiency,

-Being economical,

-Air pollution.

Thanks to the increasing possibilities with the development of technology, new functions have been sought in facade systems in addition to these basic functions. These; (Gundogdu, 2020)

- The structure can be transformed according to the changing purpose of use,

- Allows flexible design,

- Responding to new functions that arise with user demands, can be listed as.

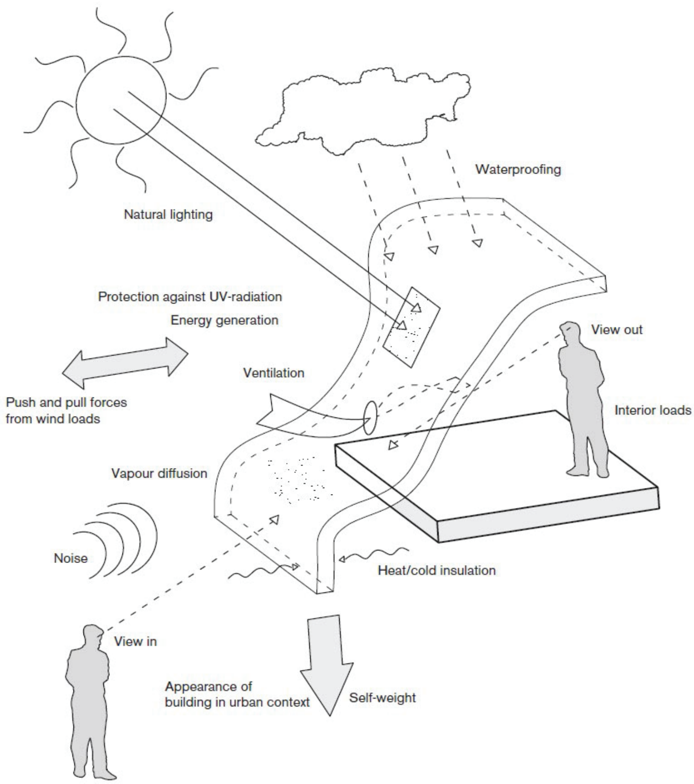

Figure 1.1. Expected Features from the Facade System (Knaack, 2014)

1.**CLASSIFICATION OF FACADE SYSTEMS**

The first factor that building structures come into contact with is the facades. Facades contain complex design elements. We can limit the facade systems that we can consider as decorative and/or functional according to their materials, carrier properties, cladding properties and kinetic status. Since the facade factor is a part of the building envelope in the building system consisting of different units, their relations to the units belonging to the facade as well as to the building's own units should be considered comprehensively. Changing any component of the building system affects the entire system.

1.1. **Facades by Material**

In the process from the past to the present, quite a variety of applications are seen on the facades. Materials such as stone, adobe and brick have been widely used for many years in the past, as they are more resistant to environmental effects, fire and require less maintenance.

In the period from the 19th century to the present and still continuing, the material was planned in advance according to the desired use in the design with the developing technological possibilities and even its internal structure was reorganized (Erinç, 2002). Today, in addition to these materials, briquettes, gas concrete, gypsum-based panels, precast concrete panels and glass panels are widely used (Orbay, 2019).

With the direct use, processing or conversion of organic and inorganic materials, a large number of variations can occur in the use of materials. Material, which is one of the main factors that gives identity to facade designs; color creates a harmony with light and shadow.

Figure 1.2. Examples of Using Material on the Facade

1.2. **Facades According to Carrier Properties**

Facade systems; with building components that resist vertically and horizontally against environmental effects such as sun, rain, earthquake, wind; It consists of building envelope components that provide conditions such as weather conditions, thermal, acoustic, fire resistance. The facade systems showing the load-bearing feature are a part of the carrier system of the building. Load-bearing walls are generally masonry walls and vertical load-bearing elements formed by masonry blocks dry or with mortar (Arun, 2018).

With the ease of application brought by the opportunities used with today's technology, the application of masonry structures is not as common as it used to be. Mostly, non-bearing facade systems are seen. Facades are structural systems that carry their own weight together with the loads acting on them.

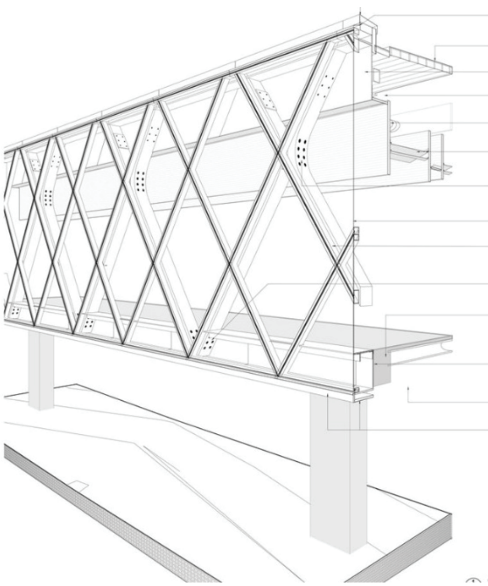

Figure 1.3. Example of Facade with Carrier System

1.3. **Facades According to Cladding Features**

Curtainwall; it can only be defined as the outer wall that carries its own load and it is connected to the carrier system on each floor. Curtain facades are non-load-bearing outer covering systems, which are independent of the building carrier system and consist of elements that are clad on the exterior surfaces of the building but transmit the load, and that provide the relationship of the building with the external environment by acting as a two-way filter (Hasol, 2009).

Other features expected from the curtain wall, which is responsible for fulfilling the separating function of the outer wall, are to provide sufficient light penetration into the interior, to provide heat, water, smoke and gas insulation, to create a suitable environment against the undesirable effects of the sun, to resist fire, to provide indoor air intake when necessary. can be counted as being easy to clean.

Curtain walls are non-bearing walls for the exterior walls of the building. The facade is an integral part of the exterior form and is thought of with a load-bearing system in the buildings. Sometimes facades that help the structural system are applied, and sometimes curtain wall systems that are made in terms of aesthetics are preferred.

1.4. **Facades According to Their Kinetic State**

With the effect of environmental stimuli, the facades in the building should be able to adapt to sound, light, noise, climatic and other physical conditions. Energy gains are higher in flexibly planned designs than in structures that are closed to change. Kinetic architecture can be defined as the state of being variable in terms of position, form and movement of the structure or its components (Madeleen, 2007). Kinetic behavior in architecture is a progressive methodology that moves some parts mechanically or through sensors while maintaining the overall structural integrity of an outlined design. The state of being kinetic, which incorporates time into the design, refers to structures that have real mobility and the ability to change geometrically (Youssef, 2017)

Figure 1.4. Montreal Olympic Stadium

Figure 1.5. Interior View of the First Roof of the Montreal Olympic Stadium

1.5. Effective Factors in Facade Design

The facades that form the identity of the buildings, besides being a building element, act as a filter in order to balance the indoor and outdoor features in order to provide suitable conditions for the building. With the benefits of new production techniques and technological developments that started with the industrial revolution, integrated systems can be created with different material compositions and construction techniques in buildings. While creating the facade designs suitable for the buildings, the factors related to the internal and external environment are classified according to the literature (Figure 1.6).

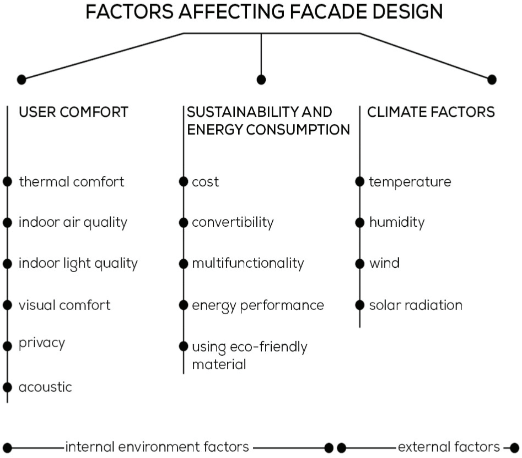

Figure 1.6. Factors Affecting Facade Design

2. ADAPTIVE ARCHITECTURE

2.1. Definition of Adaptive Architecture

Adaptive, as a word meaning, means adaptable, related to change, able to change according to environmental effects, adaptable. The term ‘adaptation’ is widely used in architecture in relation to the changing morphologies of architectural structures. According to Lehman, the purpose of adaptive architecture is synchronization. Architecture becomes a flexible filter that synchronizes behavior, whether it is the environment, the building, or the user (Lehman, 2016).

Environmental conditions directly affect the human experience and how building occupants perceive and interact with the world. In order for the spaces created to serve their functions as efficiently as possible and to provide comfort conditions, light, sound, temperature, etc. must be able to adapt to physical conditions such as Architects using new technologies are not as attached to traditional ideas as they used to be. Walls can move, roofs can be folded, and structures can rotate.

In adaptive architecture, the desired conditions for indoor and outdoor spaces are planned in advance. In response to environmental changes, the main goal is to provide the most suitable environment in sync with these conditions. In this context, we can state that reactive architecture is a more inclusive concept for adaptive architecture. In order to adapt, it is necessary to perceive environmental changes and react to these changes. If the system is designed to synchronize with and adapt to certain conditions, reactive architecture can also be specialized as adaptive architecture. Adaptive architecture; While providing energy conservation of buildings designed to adapt to objects, users and the installed environment, it contributes to creating a sustainable cycle. The important thing here is to create adaptive surfaces with an innovative facade understanding against environmental effects.

2.2. Biomimicry Supported (Bio-climate) Facade

Although different terms such as biodesign, bionics, biomimesis, bio-inspiration are used, all the terms mean the same. The inspiration for these terms, which are used in different fields, is nature (Atawula, 2016). Mankind has been interested in nature for thousands of years. Studying nature, discovering the potential of nature and applying them to architecture, engineering, medicine, transportation, textile, communication, etc. transferred to their designs in the fields.

Defining architecture as an imitation of nature, Vitruvius emphasized in his work titled “Ten Books on Architecture” that human beings who imitate swallow nests build shelters from mud with thin branches, and that they develop their shelters by learning new things day by day from nature that can be imitated (Figure 2.1.) (Türk, 2018).

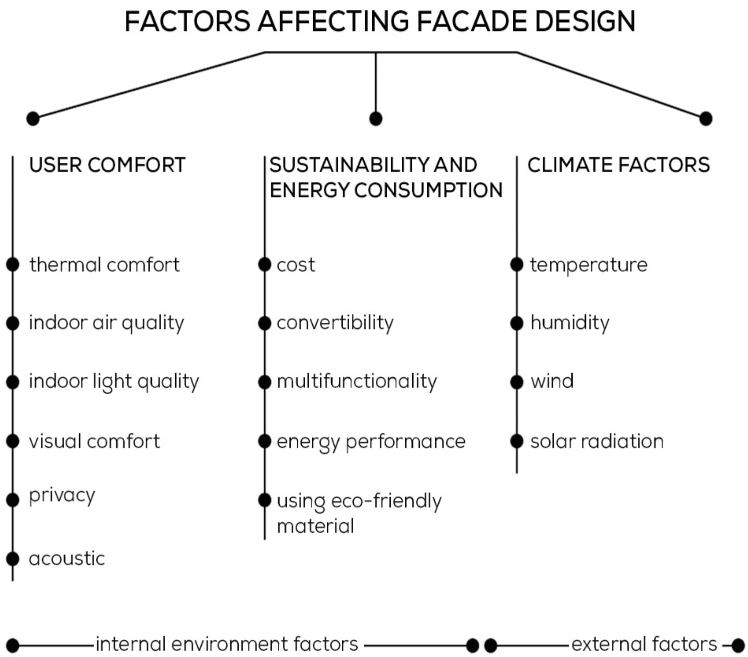

Figure 2.1. Structures and their counterparts in nature (Sorguç ve Selçuk, 2007)

With the effect of technological developments, biomimetry has increased its use in the field of architecture over time (Figure 2.1.). This design method, which is created by observing and imitating nature, is planned visually and functionally. Considering its relationship with architectural elements, systems such as spider web and bird's nest can be applied on the carrier of the facade in facade design; Based on the color variations of the cuttlefish or chameleon, LED facades whose color can change according to the weather, density or temperature of the region can be applied. In addition, if we look at the areas where biomimicry is applied functionally, the biological structure of animal skins and its properties such as heat preservation on the facades of the buildings, being a sunlight reservoir, balancing the wind, and preventing fire can be applied under the name of energy conservation.

2.3. Biomimicry Supported Facade Applications

The Eiffel Tower and Crystal Palace structures, which are the first examples of biomimicry in architecture, are based on the imitation of nature. Botanist Joseph Paxton, inspired by the lotus flower he studied, designed the Crystal Palace in 1851 (Figure 2.2.).

Inspired by the bifurcated structure on the lower leaf of the lotus flower, the structure was built by placing glasses on a steel rib system (Eggermont, 2007).

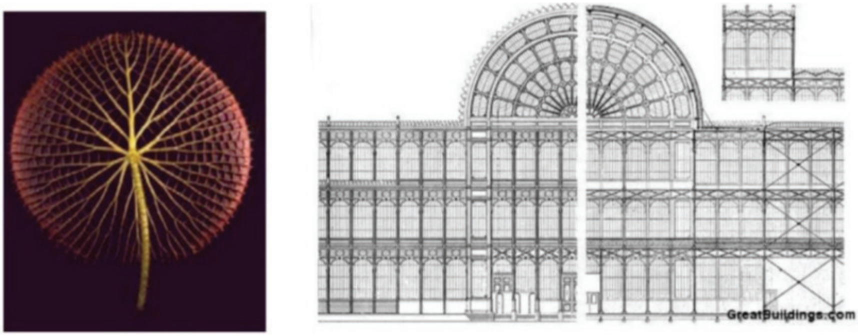

Figure 2.2. Nilüfer Çiçeği Yapısı ve Crystal Palace (Abdou, Abd El-gawad ve Eldin, 2016)

Gustave Eiffel built the Eiffel Tower in the late 1880s, inspired by the researches of the anatomist Hermann Von Meyer and engineer Karl Cullman on the femur, the lightest and most resistant bone of the body (Figure 2.3.). The structure of the thighbone inspired the tower to support off-center loads (Eggermont, 2007).

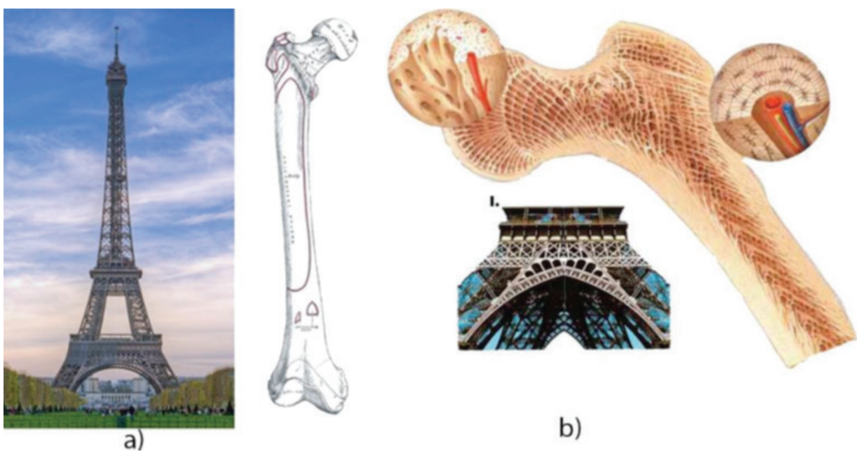

Figure 2.3. (a) Eiffel tower (url 4) (b) Thigh bone (url 1)

The office and residential building, which was built by taking the ventilation system of the termite towers as an example, can be seen in Figure 2.4. It is stated that thanks to this method, millions of dollars of energy savings were achieved in the first five years of the building.

Figure 2.4. East Gate Building and Termite Towers (url 2)

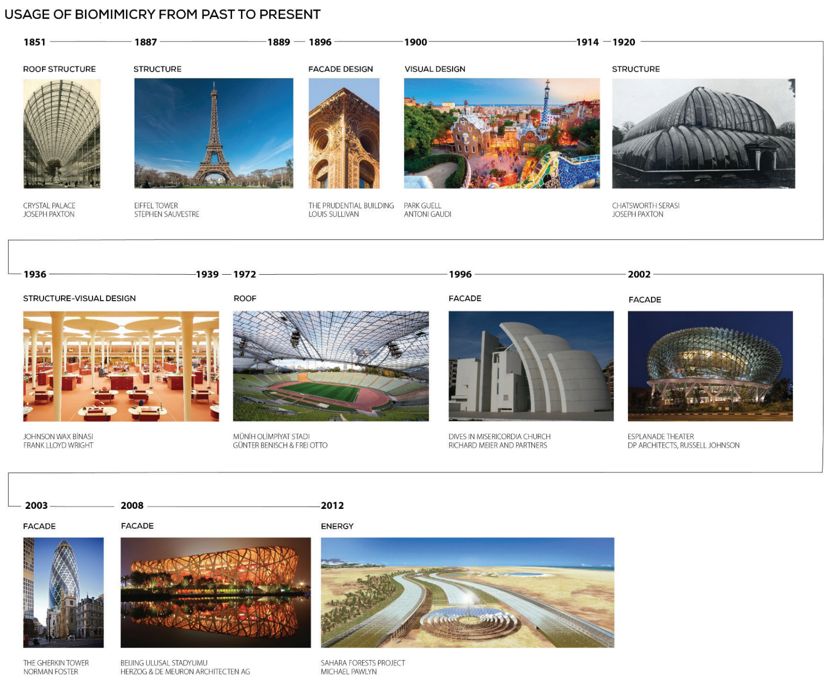

Figure 2.5. The Historical Use of Biomimicry in Architecture (İleritürk, 2016)

2.4. Advantages Of Adaptıve Archıtecture

Adaptive Architecture is a contemporary approach that centers the users of the space and provides a sustainable living environment. There are many factors in the micro and macro area where adaptive architecture is affected. It can be said that the features of adapting to the environment have also improved with the effect of developing technology opportunities in architecture. The knowledge in architecture is constantly renewing itself with new design and application methods. Structural changes in architecture should be shaped according to the needs of the users. If this system is planned to act in sync with various environmental conditions and adapt to them, reactive architecture can also be specialized as adaptive architecture.

The use of adaptive architecture provides numerous advantages in many areas depending on each other. As a result of these formations, less mobilization is applied in the projects, construction times and disturbing effects (noise, environmental pollution, etc.) are reduced. Projects can be completed in a very short time thanks to fast, planned and portable systems. The fast construction time can also minimize the occupation time of the land. Thus, it is aimed to reduce environmental pollution in a reasonable amount and to realize an effective construction process. Adaptive facades can improve the energy efficiency and economy of the building, thanks to their ability to change their behavior in real time according to indoor-outdoor parameters through materials, components and systems (Romano, 2018).

Buildings modernized with adaptive architecture are evaluated as a whole at all stages. Energy calculations are made with the opportunities provided by data processing technologies and it is aimed to create an energy efficient structure by determining the optimum values. For this reason, factors affecting each other (light, sound, wind, etc.) are considered together and their effects on users are calculated. In this way, the relationship between buildings and people is given priority. In the architectural design of the future, these relationships will become increasingly important. It provides an opportunity to seek innovative solutions without ignoring the social dimension of architecture. The use of construction materials required for construction is also planned in a way that minimizes wastage thanks to the adaptive architecture. The preferred materials are an important factor that increases the value of the building and determines its performance.

2.5. Adaptive Facade Systems

Adaptive facades effectively optimize environmental conditions and provide suitable conditions for the users of the space. In urban areas, facades are often the surfaces with the greatest potential for the integration of renewable energy generation components (solar PV, thermal, piezoelectric, etc.) (Loonen, 2015). Different types of adaptable facades used today are seen and their number is increasing.

As a basic principle, adaptive facades can actively sense and control the energy flows between indoor and outdoor spaces. They can adapt their existing features to the current situation in order to increase indoor comfort and reduce energy consumption. In order for adaptation to be implemented, it is first necessary to perceive the changes in the environment and to be able to react to these changes.

This analysis method, which is based on the variability in nature, which is the interest of architects, designers, natural scientists and biologists, is designed by being inspired by the ability of living things in nature to adapt simultaneously in response to environmental data. As a result of interdisciplinary studies, the way in which the outer surface of the living things in nature is compared to the outer surface of the structures, is an important step in creating the ways for the building to react to environmental effects.

When examining the facade performances of interactive buildings, there is a situation of establishing an active dialogue that can adapt to changing parameters simultaneously and continues according to both environmental stimuli and user needs, rather than a single-direction movement. Interactive architecture; It is the art of establishing a relationship between two active parties (which may be human or built parts) involving two-way communication (Yiannoudes, 2016). While a continuous and active dialogue with the user is at the forefront in interactive architecture, conditions are predefined in adaptive architecture and in this way it is aimed to establish a synchronization.

These two apps have much in common when it comes to reacting. Not every reactive architecture is interactive, but every interactive architecture is reactive. It can related with the basis of adaptive-interactive-reactive relationship forms used in architecture with the theory of cybernetics. This theorem formulates itself through syntheses of information and machine-object communication.

'Responsive' literally means to react quickly and positively to someone or something. The first person to coin the term 'Responsive Architecture' was Nicholas Negroponte in the late 1960s. Negroponte recommends using computing power to achieve higher performance in spaces and structures, and argues that architectural structures should be designed as responsive, adaptive machines.

Reactive architecture is based on the ideas of interaction, communication and adaptation to situations with the system that gives feedback to the user and the environment. In common terms, reactive architecture can be defined as an architectural type or structure that can show the ability to change its form and reflects the environmental conditions that constantly affect it (Sterk, 2003).

Figure 2.7. The Aegis Hyposurface, Dialogue with the Participant (url 3)

One of the examples of an architectural element, a surface transforming and adapting itself by following the movements of the user, is dECOi – Figure 2.7., designed by Mark Goulthorpe. The Aegis Hyposurface project seen in Fig. The smart surface designed in the project is created with a pneumatic mechanism, and with the help of its sensors, it can digitally compare data such as movements, density and sound level in the environment and change its direction or form accordingly.

Designed for the 2014 Sochi Olympics, this pavilion with a kinetic structure, designed on the building at the entrance of the Olympic Park, is designed to scan the faces of the visitors in the photo booth inside the building and reflect them on the facade. The responses given by intelligent systems and materials used in adaptive facade architecture can be pneumatic, chemical, magnetic, natural, cognitive, mechanical, etc. reactions can occur.

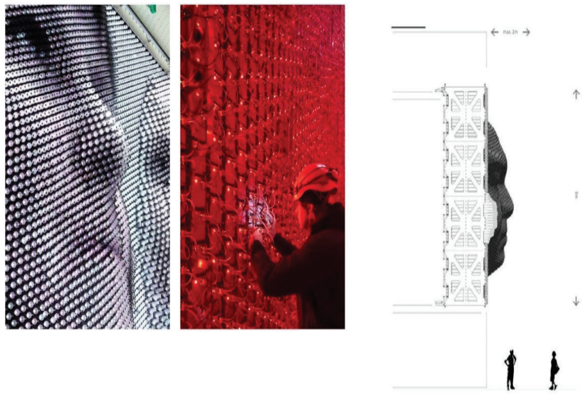

Figure 2.8. The Aegis Hyposurface, Dialogue with the Participant (url 3)

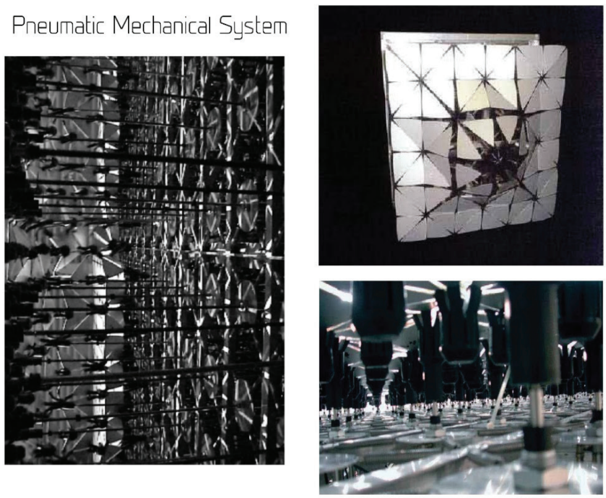

Figure 2.9. Mega Faces Facade Details, Asif Khan (url 4)

Figure 2.10. Mega Faces Front View, Asif Khan (url 4)

CONCLUSION

Today, the demand for innovative building materials is increasing day by day in the construction industry and new steps are taken to produce sustainable solutions. In this sector, which is being shaped by materials, studies on sustainable-energy efficient buildings have become widespread in order to make cities more livable, to meet their energy needs, to provide user comfort and to be sensitive to environmental resources.

Until recently, the ability of sustainable structures to adapt themselves to these changing conditions with the change of environmental conditions under the influence of the climate crisis was defined as having point-sensing sensors, actuators, energy-converting high-tech and complex automatic mechanisms. The low-tech and no-technology passive strategies of adaptive façade design based on material sensibility were still in their infancy. Passive strategies minimize energy and material use while maintaining passenger comfort.

Adaptive construction systems are created by blending the smart properties of materials with traditional construction technologies and integrating additional functions into these technologies. The future of advanced systems is pretty clear. Recently, 3D printing techniques within the scope of adaptive architecture, smart materials or the integration of biological organisms into building materials, etc. studies diversify their application areas and adaptation forms. The use of natural systems alongside mechanical systems affects the performance of adaptive facades and reduces building operating costs. With the principles of the adaptive facade architecture approach, it transforms from a static structure that consumes the energy around it to a dynamic system that can adapt itself to environmental conditions, inspired by nature and reacts. The amount of energy required to adapt the systems is produced from natural resources and the complexity of maintenance services is the most important factor affecting the performance of adaptive facades. By using biomimicry, it can be interpreted as the ability of the building shell to have a natural skin surface effect.

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Url-3: **<**https://elojosalvaje.com/2010/09/24/hyposurface/&gt> (Erişim Tarihi 16.07.2022).

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CHAPTER 3

EVALUATING THE RELATIONSHIP BETWEEN FRACTALITY AND IMAGEABILITY PRINCIPLES FOR SUSTAINABLE URBANISM: AN EXPERIMENTAL STUDY

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Introduction

The mental image is a silhouette of the space formed in the mind due to interpreting and organizing environmental information and sensations. This process is known as the perception and cognition process. In this process, the environmental characteristics that attract a person's attention convert to information and are recorded in memory as a mental image. The mental image formed in easily perceived and cognized spaces is more permanent and remembered more clearly. In the formation process of the mental image, the working process of memory is among the essential issues to be examined. Generally, people perceive, recognize, and save the environmental characteristics that are easily classified, ordered hierarchically, repeated serially in proportional harmony, and diversified free from chaos and monotony more easily and quickly in memory (Klinger and Salingaros, 2000). At the same time, environments designed with fractal geometry principles have these properties. Fractal geometry, which is the geometry of nature, defines the transition from ordered to disordered (Mandelbrot, 1982: 170). Fractal geometry and human mental functions are interrelated. Fractal geometric objects contain perceptual properties suitable for human nature. These properties help form the mental image clearly and remember it quickly. Fractal geometry is described by a numerical expression defined as the fractal dimension. As a result of the above descriptions, this study has two basic hypotheses: "as the fractal dimension increases, the imageability increases" and "the characteristics that cause the formation of the mental image match with the characteristics of fractal geometry." The conceptual framework and hypotheses of the study are explained in Figure 1.

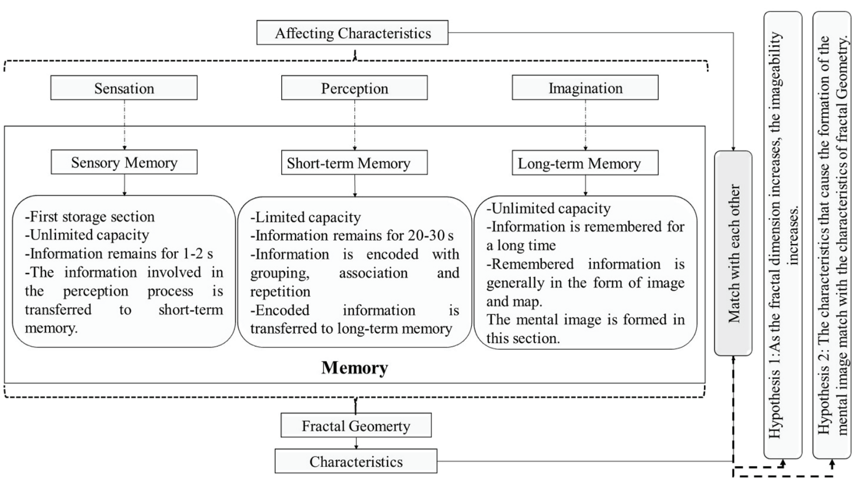


Figure 1. The conceptual framework and hypotheses of the study

In this study, the imaginability of space was evaluated through fractal theory. Previous studies on the imageability of the space were only questioned with subjective methods; however, an objective method was proposed in this study, and its accuracy was reinforced with a subjective method.

Mental Image and Memory

Mental image" is defined as the representative of space in the mind and is generally considered a perceptual and cognitive concept. People convert space view to cognitive schemes by interpreting with instant emotions and old information to memorize the space's image quickly and effectively (Lynch, 1960: 9). Downs and Stea (1973) define the mental image as "cognitive mapping." According to their description, "The cognitive mapping is a process composed of a series psychological transformation by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in his everyday spatial environment." This process occurs in three stages: sensation, perception, and imagination. In the sensation stage, environmental information is taken into the cognitive process. This stage is known as the initial stage of the imagination process. In the perception stage, sensory data are evaluated as a whole. In the imagination stage, sensory data turn into a meaningful perception (Downs and Stea, 1973: 8-26). Observing, understanding the environmental information, and storing this information in the mind as a mental image is performed through perception. The perceived information is evaluated in the mind, creating the mental image (Bell et al., 2001; Smith, 2002; Siegel, 2006; Wells et al., 2006). Perception is the essential stage of the mental image formation process. The perceptibility quality of the space plays an important role in the permanence and clearness of the formed mental image. The spatial organization, visual features, identities, semantic and symbolic values, familiarity levels, positions, and functions of the urban elements affect the perception and the mental image (Lynch, 1960; Appleyard, 1969; Weisman, 1981; Evans et al., 1982; Gärling et al., 1982; Moughtin et al., 1996; Tlauka and Wilson, 1996; Başkaya et al., 2004). Mental imagery performance is related to the individual's memory functions (Egan, 1992; Barsalou,1999). Memory consists of three main storage sections: Sensory memory, Short-term memory, and Long-term memory. Environmental information taken with sensory organs first reaches to sensory memory through the nervous system. The information remains in this section for 1-2 seconds. If the information is not transferred to short-term memory within this period, it will be lost and forgotten. Since short-term memory's storage capacity is limited, old information is forgotten when new information is transferred to this section. The time that information stays in short-term memory is 30 seconds at best. But the information taken into the cognitive process passes to long-term memory and then turns into a mental image by combined with the old information stored in the memory and individual characteristics (Atkinson and Shiffrin, 1971; Ranganath et al., 2005). Transferring information from short-term to long-term memory constitutes the most important stage of mental work. Long-term memory has unlimited capacity. The information transferred here stays in the memory for a long time and can be easily remembered when recalled. The main reasons for transferring information to long-term memory are summarized below (Ashcraft, 1989: 320-331):

- Being interested in or liking
- Encoding the information
- Organizing and classifying the information
- Repetition
- Experience

Consequently, the mental image is formed in long-term memory. Easily classified and encoded information is transferred to Long-term memory. Also, the scenes that may be of interest and liking for a person transfer to long-term memory. So, the formed mental image is stored for a long time and can be recalled quickly, if necessary.

Visual Perception

Visual perception constitutes an important part of the perception process. Therefore, the visual qualities of the elements in the space greatly affect the perception and thus the mental image formation (Kaplan, 1987; Cornell and Heth, 2000: 68-83). Lynch (1960) classified the visual elements that cause the formation of the city image into five elements: paths, edges, districts, nodes, and landmarks. According to Lynch's theory (1960), buildings that can be defined as "Landmarks" play a significant role in the imageability of urban spaces. The architectural characteristics of buildings, such as form, geometry, color, size, ornaments, and details, help to form a permanent mental image (Lynch, 1960: 46-47). The architectural characteristics of buildings that affect mental image formation are examined under three main headings in line with the hypothesis: Geometry, Diversity, and Hierarchy. In visual perception analysis, it is possible to classify all visual features of buildings under these three features.

Geometry

Geometric forms and combinations have importance in the perception stage. Salingaros (2005) states that the human brain performs three important actions in the spatial perception process (Salingaros, 2005):

1. Generating combinations between elements in space,
2. Trying all possible geometric combinations,
3. Choosing the most systematic and understandable combination

The interaction of the structures containing curved forms with the environment is at the maximum level, and their visual connection with other elements is strong (Salingaros, 2005). At the same time, while circular and curved forms on structure facades make the perceptual process easy (Krier, 1984:16-22), rectangular and sharp forms are hardly perceived (Peitgen, Jürgens ve Saupe, 1993: 376). In this context, traditional architectural styles are adopted by people at a higher level than avant-garde styles (Stamps, 1999). In modern architecture, simple, uniform, straight and sharp lines and rectangular designs cause the space to be difficult to perceive and keep in memory (Salingaros, 1997).

Diversity

Another essential issue making perception and mental image formation easy is visual diversity. The diversity of architectural elements, ornaments, and details on the building facades positively affects the perception process. As diversity increases, the individual's interest increases, which helps him/her save the image in memory (Stamps, 1999; Stamps, 2003). The increasing number of details and their differences in building facades increase visual diversity (Berlyne, 1970). Formal differences in horizontal and vertical axes, rhythm, partitions in the horizontal plane, the density of windows and doors and their formal differences, recesses-protrusions, balconies, and eaves help increase facades' visual diversity.

Hierarchy

Space is perceived because of comparing elements with different scales and sizes. The hierarchy is the balance between order and diversity in size and form. Hierarchical organization is an important feature that makes mental functions easy. Hierarchy is defined in two different ways (Alexander, 2000; Salingaros, 1995, 1997):

1. Size: It is the scaling hierarchy between components. It means the proportionality of small, medium, and large components together.

2. Form: It means the self-similarity of the components between scales in terms of shape.

The structure is immediately perceived when the relationship between the size of elements that make up the structure is realized through a defined rule. Brain classifies similar elements in a single category and records them without any information confusion in hierarchically ordered spaces. Also, the person remembers the number of elements in each category more easily and quickly (Salingaros, 1997). Details in the architecture associate large-scale units with sub-units, thus providing connection and integrity between units. The loss of sub-details, such as decoration and ornaments in modern architecture, causes the hierarchical scale to disappear. So, the perception becomes difficult (Salingaros, 2005).

Fractal Geometry and Memory

Fractal geometry defines shapes that are made up of minimized parts of the whole. In short, irregular details or patterns are repeated on an even smaller scale. Fractal geometry is concerned with the concept of self-similarity and order-disorder in nature. The most important feature of fractals is that forms similar to themselves are repeated in hierarchical order, and the diversity in the pattern is created through certain rules. Fractals are created by repeating patterns, shapes, or a mathematical equation, and this formation depends on the initial form (Salingaros, 1999; Alexander et al., 1977). Some well-known fractal structures are shown in Figure 2.

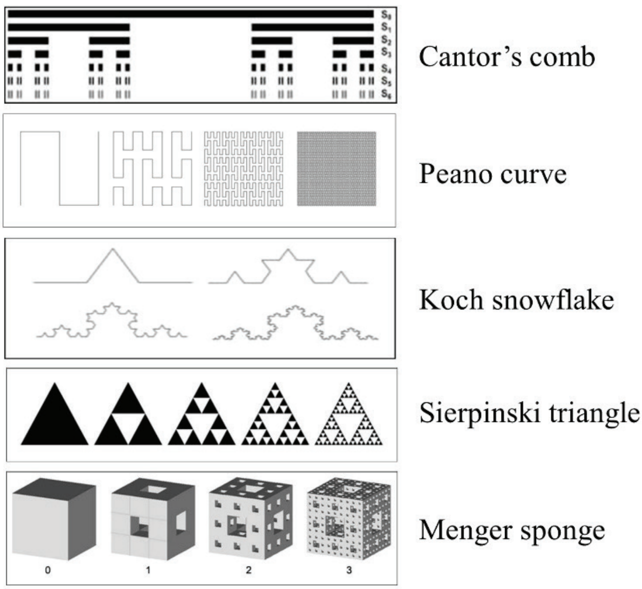


Figure 2. Examples of fractal structures (Author)

Fractals are measured with a non-integer parameter and fractional size called fractal dimension. Fractal dimension refers to a value that numerically describes the detail richness of a structure. The comparison of Euclidean and Fractal dimensions is shown in Figure 3.

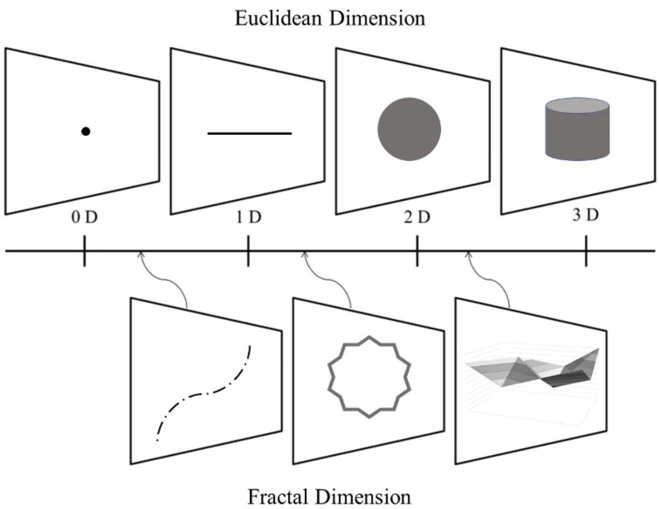


Figure 3. The comparison of Euclidean and Fractal dimensions (Author)

In 2D surfaces, the fractal dimension, which represents the level of irregularity of the structure, varies between 1 and 2, and as it approaches 1, the texture of the structure becomes less detailed. The fractal dimension is a quantitative value used to measure the structure's irregularity level and reveal its hidden harmony and symmetries. Geometry plays an efficient role in human perception and the mental working process. According to some studies, nature's geometry is Fractal geometry. Structures shaped by fractal geometry can positively affect the individual's visual perception and cognitive process (Mandelbrot, 1982; Mesev et al., 1995; Bovill, 2000). Fractal geometry has a hierarchical order, rhythm, and diversity specifications. Such structures offer visual quality and positively influence the individual's perception (Salingaros, 2000; Taylor, 2006). Since the principle by which nature is regulated is the fractal principle (Mandelbrot, 1982: 174), people expect to perceive their environment on the same principle.

Moreover, the human brain consists of hierarchically arranged modules and a complex system. This structured system is repeated with different scales and forms a fractal structure. Because the human brain is intrinsically fractal, it perceives forms with fractal geometry more easily. As a result of this anatomical feature, people tend to imagine fractal forms naturally. There appears to be a certain resonance between the brain and forms with fractal geometry. The brain constantly calculates the characteristics of our environment and evaluates the properties necessary for our survival, so this resonance has profound meaning (Salingaros, 2012). Generally, the brain generates codes and algorithms to record environmental information.

Shortcodes are easier to save in memory. When a person looks at fractal structures designed with defined principles such as hierarchical order and self-similarity, the length of the code produced by the person's brain decreases. Therefore, sensory information from the environment is transferred from short-term memory to long-term memory more easily and quickly (Mikiten et al., 2000). Also, when the person's brain generates an algorithm while trying to perceive a fractal structure, it can use the same algorithm when facing other fractal structures. Thus, the perception process becomes faster and easier. During the encoding of information, the brain can classify similar elements that are repeated horizontally or vertically in fractal structures under a single category. The information can be easily remembered because the information density transferred to the brain is low (Salingaros, 2010).

Fractal Geometry of Buildings

According to Bovill's (2000) research, continuity, details, non-Euclidean geometry, and natural forms help architects to design fractal structures. People appreciate the structures designed in this way. Bovill (2000) compared the fractal dimensions of Frank Lloyd Wright's Robie House and Le Corbusier's Villa Savoye using the images of the building facades. The fractal dimensions were calculated by the box-counting method. Robie House's fractal dimension was calculated as 1.441, and Villa Savoye's fractal dimension was 1.333. As a result, the Robie House's fractal dimension was higher than Villa Savoye's. According to Bovill's (2000) research, recesses and protrusions, the mobility in the roof forms, and the details used in the Robie House gave this building a richness of detail. However, using sharp and straight lines in Villa Savoye has caused a lack of natural visuality and low detail richness (Bovill, 2000). If a structure is decorated with similar and main mass-shaped small parts, it is designed according to fractal geometry's principle. The repetition of similar elements on the building facades and the reduction by the scale and detailing of the facade elements while preserving their formal similarities increase the fractal dimension of the building facade (Goldberger, 1996). Salingaros (2001) states that details and ornaments in building facades strengthen human-environment interaction. The diversity of elements in form and number, ornaments, and decorative texture on the building facade divide it into sub-units of different scales and create a fractal structure. Losing the details on building facades and focusing on the basic shape of the building with sharp and straight lines causes the loss of fractal geometry in architecture (Salingaros, 2001). When the characteristics of buildings designed with fractal geometry principles are examined, the following features can be summarized (Mikiten et al., 2000):

- Diversity of size and form

- Hierarchical proportion
- Self-similar elements with different sizes
- Contrast and symmetry
- Coherence and order
- Combinations from small size units to large
- Components with human scale, varying in size between 1cm and 1m
- Connection and balance between units
- Harmony

Methodology

The study used images of building facades as the data set. The images were taken from the building facades in Ürgüp, Uçhisar, Göreme, and Avanos districts located in the Cappadocia region in Turkey. The reason for choosing this region is that it has various building types with different architectural styles, including traditional, vernacular, and modern architecture. Thus, a data set of different architectural styles was created, with 20 images taken. The images were taken at a right angle, between 12:00 - 14:00, for five days. All information, such as semantic values and advertisement contents on building facades, was deleted. Also, noticeable and catchy colors were eliminated. The assessments in the study were made in two stages; objective and subjective. In the objective assessment, the fractal dimensions of the building facades were calculated based on the images, and in the subjective assessment, the memory performances of the participants were examined.

Calculation of Fractal Dimension

Fractal dimension (D) is a numerical value that describes the wealth of detail and is a statistical quantity that describes how much a fractal structure fills space and is an effective index for measuring the properties of complex surfaces. Mandelbrot (1982) proposes Box-counting to calculate fractal dimension as explained in Equation 1 (Mandelbrot, 1982: 171).

Equation (1)

$$D = \lim_{r \to 0} \left[\frac{\log N_r}{\log \frac{1}{r}} \right]$$

The Box-counting method is one of the methods commonly used to measure fractal dimension. In this method, the area containing an object is divided into boxes of a certain size, and it is determined how many boxes the object fills. In Equation (1): r is box size, and N_r is the total number of boxes. So, the fractal dimension (D) can be estimated from the least square linear fit of $\log(N_r)$ versus log(1/r) (Min and Peng, 2013). Today, different computer software is used to calculate the fractal dimension. In the fractal dimension calculation, attention has been paid to ensuring that the resolution and pixel size of all the images used are the same. The fractal dimensions of the images are given in Table 2.

Assessment of Memory Performance

<u>*Memory Tests*</u>

Visual information is recorded in the mind as neural representatives after passing through the memory process in mental image formation. At this stage, the visual memories of individuals gain importance. Generally, four different methods are used to evaluate the relationship between characteristics of place and memory performance:

1. *Self-Report test:* In this test, participants are asked verbally about the characteristics that they remember related to the place they visited or saw or the problems they faced in wayfinding, and then the verbal expressions are grouped under headings (Lawton, 1996).

2. *Sketch Map:* In this test, participants tour a virtual or real place. Then, they are asked to sketch the elements they remember during their tour (Lynch, 1960; Evans, 1980; Billinghurst and Weghorst, 1995: 1-8).

3. *Recall test:* In this test, after the tour in the virtual or real place or after the showing of images of the place, participants are asked verbally or in writing about the most remembered and remarkable elements and properties of the place (Kim and Penn, 2004).

4. *Recognition test:* In this test, after the tour in the virtual or real place or after the showing of place images, the images of the place are shown again to the participants, and they are asked to select or arrange the images they recognize (Cohen, 1980; Evans et al., 1984; Deakin, 1996; Fontaine and Denis,1999: 83-94).

<u>*Recognition Test*</u>

In the second stage of the study, the recognizability of the images and the physical characteristics that make images recognizable were examined by the "Recognition Test". Because the "Recognition Test" provides an easier test system for participants than other tests, this test was preferred for evaluating the participants' memory performances in this study. Information of participants is given in Table 1.

Table 1. Participants

	N	Age Range	Familiarity	Gender	N	%	Age Range
Participants	155	20-30: % 29,68 31-40: % 33,55 41-50: % 36,77	First-time visitor	Male	76	% 49,03	20-30: % 28,95 31-40: % 34,21 41-50: % 36,84
				Female	79	% 50,97	20-30: % 30,38 31-40: % 32,91 41-50: % 36,71

N: Subject number, %: Percent

The age range of participants is between 20 and 50. Since the study aims to evaluate the relationship between fractality and imageability, there was no limitation on participant's characteristics such as age, education, and culture. But familiarity is among the critical factors affecting perception and memory performance. So, participants who saw the building's facades for the first time were preferred. In the study, computer technology was used as a presentation technique. The images were shown to participants in two stages. Primarily, the images were shown individually, and each image was paused on the screen for three seconds. The display of the images was repeated three times. Participants were given no explanation about the purpose of the study, and they were requested to follow the images carefully. After presenting images one by one, the surveys were given to participants, and the second stage of the presentation started. At this stage, twenty images shown previously were mixed with ten images not shown, and a total of thirty images were presented one by one on the computer screen. Simultaneously, participants were asked to answer the questions in the given surveys. The survey consisted of three questions: In the first question, the recognizability of the image was asked, and they were supposed to choose one of the three options: "Yes, I recognized", "Undecided" and "No, I didn't recognize". The second question asked about the characteristics that help them recognize the image. The places we like and perceive easily create permanent images in our memory; at the same time, ugly and unpleasant scenes also create a permanent and clear image in our memory. In this context, a question about liking images was added to the survey. The purpose of this question was to compare levels of recognizability and liking. In the third question, they were asked whether they liked the image or not by choosing one of the given options: "Yes, I liked", "No idea" and "No, I didn't like".

Results

Examination of Recognizability and Liking Rates of Images

At this stage of the study, the answers given to the first and third questions of the survey were evaluated. The obtained results and the fractal dimensions of the images are given in Table 2.

Table 2. Fractal dimensions, recognizability, and liking rates

Image No.	Fractal Dimension	Frequency & Percent	Do you recognize it?			Do you like it?		
			Yes, I recognized	Undecided	No, I didn't recognize	Yes, I liked	No idea	No, I didn't like
1	1,85	N	131	16	8	99	25	31
		%	84,52	10,32	5,16	63,87	16,13	20,00
2	1,89	N	149	0	6	119	0	36
		%	96,13	0,00	3,87	76,77	0,00	23,23
3	1,82	N	128	20	7	65	61	29
		%	82,58	12,90	4,52	41,94	39,35	18,71
4	1,8	N	123	26	6	76	19	60
		%	79,35	16,77	3,87	49,03	12,26	38,71
5	1,85	N	142	9	4	111	22	22
		%	91,61	5,81	2,58	71,61	14,19	14,19
6	1,61	N	95	48	12	0	35	120
		%	61,29	30,97	7,74	0,00	22,58	77,42
7	1,87	N	149	5	1	74	21	60
		%	96,13	3,23	0,65	47,74	13,55	38,71
8	1,76	N	91	52	12	49	19	87
		%	58,71	33,55	7,74	31,61	12,26	56,13
9	1,82	N	114	13	28	97	29	29
		%	73,55	8,39	18,06	62,58	18,71	18,71
10	1,8	N	112	39	4	82	28	45
		%	72,26	25,16	2,58	52,90	18,06	29,03
11	1,78	N	96	42	17	120	14	21
		%	61,94	27,10	10,97	77,42	9,03	13,55
12	1,66	N	63	43	49	60	28	67
		%	40,65	27,74	31,61	38,71	18,06	43,23
13	1,79	N	121	21	13	61	41	53
		%	78,06	13,55	8,39	39,35	26,45	34,19
14	1,89	N	151	0	4	54	19	82
		%	97,42	0,00	2,58	34,84	12,26	52,90
15	1,7	N	98	51	6	20	3	132
		%	63,23	32,90	3,87	12,90	1,94	85,16
16	1,64	N	74	42	39	18	43	94
		%	47,74	27,10	25,16	11,61	27,74	60,65
17	1,71	N	68	74	13	37	39	79
		%	43,87	47,74	8,39	23,87	25,16	50,97
18	1,81	N	112	38	5	113	35	7
		%	72,26	24,52	3,23	72,90	22,58	4,52
19	1,82	N	134	15	6	107	21	27
		%	86,45	9,68	3,87	69,03	13,55	17,42
20	1,73	N	30	42	83	74	18	63
		%	19,35	27,10	53,55	47,74	11,61	40,65

Table 2 provides detailed information on a total of twenty images. The descriptive statistical analysis was summarized in Table 3.

Table 3. Descriptive statistical analysis

	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
Fractal Dimension	1,61	1,89	1,780	0,081	0,007	-0,658	-0,386

Yes, I recognized	19,35	97,42	70,355	20,919	437,686	-0,757	0,268
Undecided	0,00	47,74	19,226	12,990	168,743	0,232	-0,550
No, I didn't recognize	0,65	53,55	10,419	12,924	167,021	2,414	6,160
Yes, I liked	0,00	77,42	46,321	22,744	517,283	-0,400	-0,634
No idea	0,00	39,35	16,773	9,019	81,338	0,461	1,087
No, Ididn't like	4,52	85,16	36,904	21,899	479,569	0,673	-0,139

The mean value of fractal dimensions was calculated as 1,78. While the mean of the recognizability percentages of the images is 70.35%, the mean of the liking percentages is 46.32%. The recognizability and liking percentages for each image were compared in Figure 4.

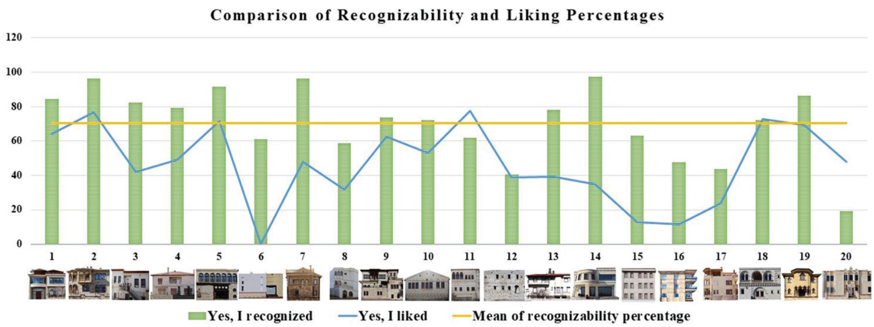


Figure 4. Comparison of recognizability and liking percentages

As shown in images 6, 7, 13, 14, and 15, there is a significant difference between recognizability and liking rates. Although the recognizability rates of these images are high, their liking rates are low. It is understood that the permanence of the mental image does not depend on the liking. According to this result, it has been determined that unpleasant and unattractive scenes can also form a permanent mental image.

Correlation Analysis

In this stage, correlation analysis was done to test the relationship between recognizability and liking of rates. Analysis results are given in Table 4.

Table 4. Correlation analysis results

Correlation			
		Recongnizability	Liking
Recongnizability	Pearson Correlation	1	,420
	Sig*. (2-tailed)		,065
Liking	Pearson Correlation	,420	1
	Sig*. (2-tailed)	,065	

*. Correlation is significant at the P<0,05 level (2-tailed).

The results show no significant relationship between recognizability and the images' liking rates since the significance level is P<0,05. Thus, a permanent and clear mental image can be formed in places that are not liked.

Regression Analysis

In this section, recognizability and liking rates were defined as independent and fractal dimension was defined as the dependent variables. After the homogeneity and normality tests were performed, a simple linear regression analysis was done separately between each independent and dependent variable. The summaries of the regression analyses are given in Table 5.

Table 5. Regression analysis results

Variables		Model Summary		ANOVA		Coefficient				
Dependent	Independent	R	R^2	F	P	B	Std. Error	β	t	P
Fractal Dimension	Model 1 (Recognizability)	0,795	0,632	30,848	,000*	1,563	0,041	0,795	38,332	,000*
	Model 2 (Liking)	0,729	0,531	20,389	,000*	1,659	0,03	0,729	55,956	,000*

* Significance level: P<0,05

According to the results of the ANOVA test, both models are significant at the P <0,05 level. However, in the first model, 63,2% of the data (R^2 = 0,632) explain the model, while, in the second model 53,1% (R^2 = 0,531) of the data explain the model. As a result, the fractal dimension affects the recognizability of the images. As the fractal dimension increases, the image recognizability increases. Thus, the first hypothesis of the study is proven.

Examination of Recognizable Characteristics

At this stage, the characteristics that help to recognize the images were classified according to the answers given by participants. The characteristics are summarized in Table 6.

Table 6. Recognizable characteristics

No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total	
Fractal Dimension	1,85	1,89	1,82	1,80	1,85	1,61	1,87	1,76	1,82	1,8	1,78	1,66	1,79	1,89	1,7	1,64	1,71	1,81	1,82	1,73		
	Frequency																				N	%
Moobility of roof	74	6	30	39	4	5	27	4	27	11	19	16	85	6	0	6	3	10	24	25	421	8,51
Geometric forms	55	34	12	36	48	65	49	66	52	29	63	30	69	131	6	12	18	78	58	4	915	18,50
Balcony and eaves	33	112	37	24	0	0	98	15	69	0	5	33	54	0	0	49	14	26	40	0	609	12,31
Details and ornaments	25	64	60	0	60	0	40	8	55	85	81	38	4	19	0	0	18	86	73	3	719	14,54
Repetition and rhythm	4	9	4	21	91	26	27	13	40	31	38	14	13	34	42	15	11	1	39	3	476	9,62
Form of windows and partitions	65	76	54	33	111	34	12	26	70	41	60	29	32	71	82	48	25	54	40	6	969	19,59
Form of doors and partitions	52	8	23	15	0	21	14	4	15	0	16	10	49	28	0	0	7	0	27	0	289	5,84
Density of doors and windows	22	55	34	22	21	0	11	13	65	20	22	10	63	55	16	17	58	0	39	5	548	11,08
Total	330	364	254	190	335	151	278	149	393	217	304	180	369	344	146	147	154	255	340	46	4946	100,00

The characteristics that helped the participants to recognize the images were evaluated in eight categories. A total of 4946 answers were given within the scope of these characteristics. As a result of the answers given, the percentage of the characteristics is shown in Figure 5.

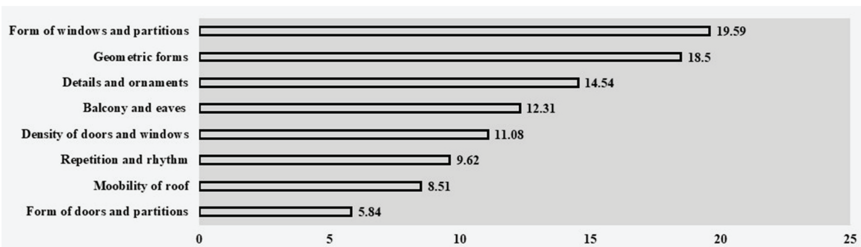


Figure 5. Frequencies of the recognizable characteristics

According to the ranking of characteristics that help recognize the images, “Form of window and partitions” is the first, with 19.59% of the answers, “Geometric forms” take second place with a ratio of 18,5%, “Details and ornaments” take third place with a ratio of 14,54%. “Balconies and eaves” take fourth place with a ratio of 12,31%, “Density of doors and windows” take fifth place with a ratio of 11,08%, “repetition and rhythm” take sixth place with a ratio of 9,62%, “Mobility of roof” take seventh place with a ratio of 8,51% and “Forms of doors and partitions” take eighth place with a ratio of 5,84%. Detailed analysis for each image is given in Figure 6.

Figure 6. Detailed analysis

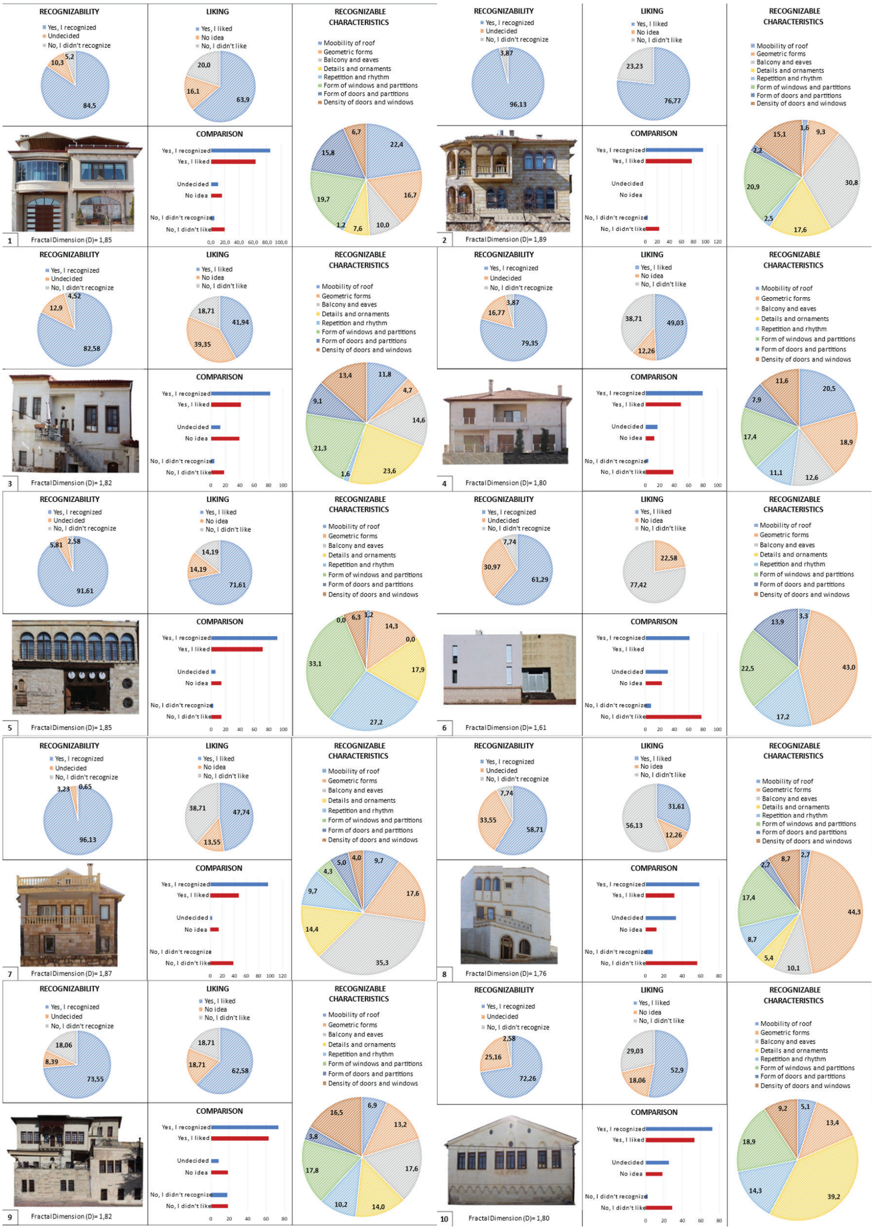
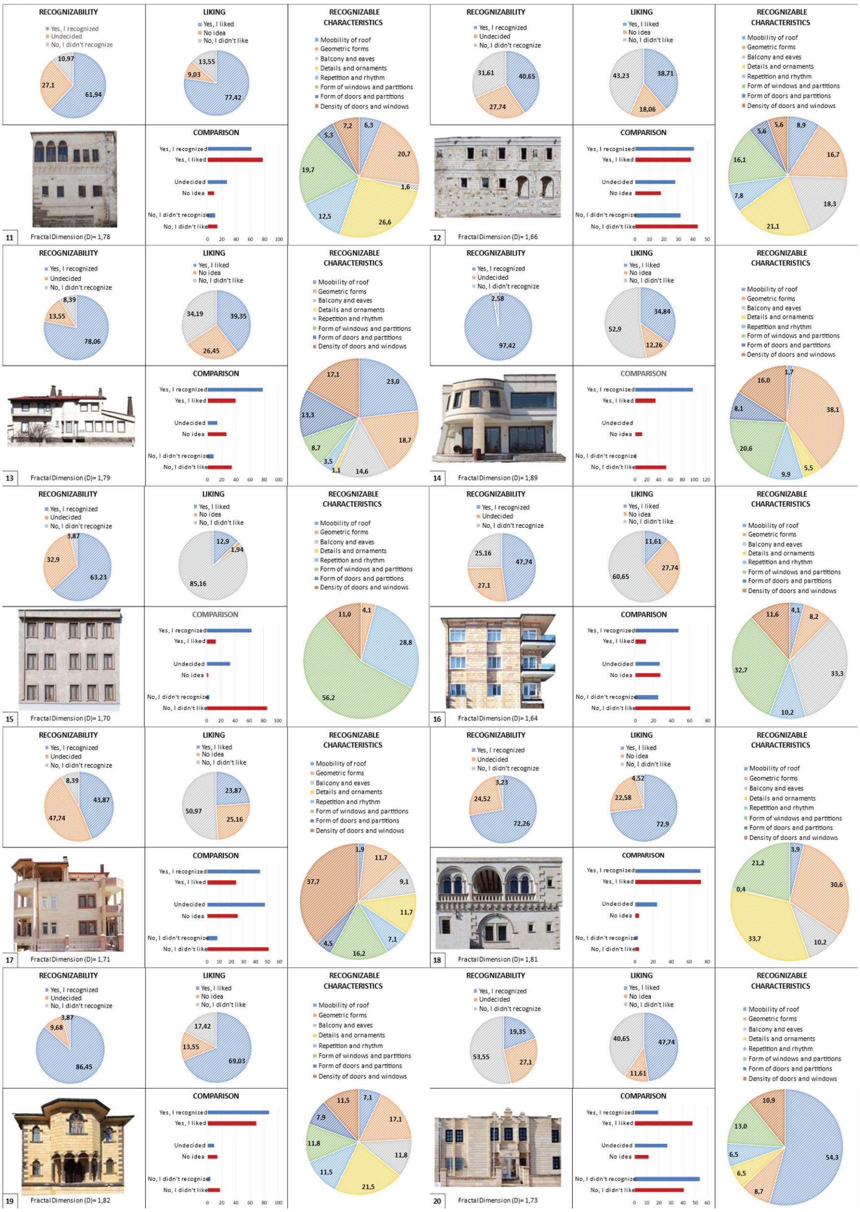

RECOGNIZABILITY
Yes, I recognized
Undecided
No, I didn't recognize
LIKING
Yes, I liked
No idea
No, I didn't like
RECOGNIZABLE CHARACTERISTICS
Moobility of roof
Geometric forms
Balcony and eaves
Details and ornaments
Repetition and rhythm
Form of windows and partitions
Form of doors and partitions
Density of doors and windows
COMPARISON
1 Fractal Dimension (D)= 1,85
2 Fractal Dimension (D)= 1,89
3 Fractal Dimension (D)= 1,82
4 Fractal Dimension (D)= 1,80
5 Fractal Dimension (D)= 1,85
6 Fractal Dimension (D)= 1,61
7 Fractal Dimension (D)= 1,87
8 Fractal Dimension (D)= 1,76
9 Fractal Dimension (D)= 1,82
10 Fractal Dimension (D)= 1,80

Figure 7. Detailed analysis (more)



Discussion

As a result, it was proven that there is a statistically significant and positive relationship between the recognition performance and the fractal dimension of the images. As the fractal dimension of images increased, the images became recognizable. Besides, three important characteristics that helped recognize the images were the form of windows and partitions, geometric forms, details, and ornaments. These characteristics coincide with the features of facades designed with fractal geometry principles. In the study, the imageability of urban space was examined only through buildings. By considering other factors affecting the urban image such as landscape, street furniture, geometry and color, more holistic research can be conducted and more comprehensive data on the imageability of urban spaces can be obtained. In imaginable spaces, the human-environment relationship is established more strongly and permanently, and in spaces with high imaginability, individuals do not experience confusion in wayfinding and so, spend more enjoyable time in these urban spaces. In previous studies examining the imageability of the space, it was seen that subjective methods are predominantly used. In this study, fractal theory has been proposed as an objective method and its accuracy was reinforced with a subjective method.

Conclusion

In urban spaces, physical components that strengthen human-environment interaction and positively influence imageability are important. The mental image, which is a dynamic phenomenon, is affected by the perceptibility quality of the space. The perceptibility of the space and the clarity and permanence of the mental image formed in the mind affect human psychology positively. The imageability of space in a systematic order creates a visual comfort for humans (Barlas, 2006). Also, the elements and designs that increase the imageability of the space help people in wayfinding. Thus, people can tour the city without stress and confusion. This study aimed to develop a new objective approach to design the imaginable spaces. For this purpose, the fractal theory, which can evaluate the qualities of the space numerically and at the same time positively affect the mental image formation, was used. The human easily perceives and remembers the cognitively appropriate information to his nature, and he can organize, make clear, and associate them in his mind. It is important to examine the instinctive factors affecting the cognitive process to comprehend the complexity of the irregular formation of the natural environment and to analyze the mental images that may occur unconsciously. Perceptual evaluation of space is influenced by subjective factors as well as partially natural, instinctive, and objectified factors. Fractal geometry as the language of nature affects the rememberability of mental image and the working process of memory positively. Structures designed with the principles of fractal geometry have high excitation potentials that affect human perceptual and cognitive processes. These stimulants can be defined as qualities such as order, harmony, hierarchy, dimensional diversity, and self-similarity. Structures with these characteristics are more easily perceived and classified in memory to be recalled quickly and easily. Moreover, the human brain has a hierarchical and fractal structure and perceives similar fractal systems more effectively. In this study, the relationship between the imageability of urban spaces and the fractal theory was evaluated. According to the obtained results, there was a statistically significant and positive relationship between fractality and imageability. As the fractal dimension of images increases, the recognizability of images increases. At the same time, it has been determined that the qualities that affect the formation of a permanent mental image and the features of fractal geometry are closely related. Consequently, fractal geometry can be used as a design tool to create more imaginable urban spaces. This study can provide some substantial information for architects and urban designers to create more imaginable urban spaces.

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CHAPTER 4

THE EFFECT OF SCHOOL OUTDOOR USE OF KINDERGARTEN STUDENTS ON SCHOOL CLIMATE PERCEPTIONS DURING THE PANDEMIC PROCESS[1]

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1. INTRODUCTION

Outdoor use is very important for children’s cognitive, social and physical development. Urban spaces should be of a quality to support this development of children. However, Buss (1995) stated in his study that cities are generally perceived as “dangerous, violent (Buss, 1995: 45)” places by children. Although this perception cannot be generalized for all cities, it should not be forgotten that ‘safety’ is an important determinant in the use of space for children. Urban parks and gardens, children’s playgrounds, site gardens are places for children to socialize, move and relax mentally.

“On the contrary, today, children are made to stay in closed spaces. These children, called “indoor children” or “digital natives” by Migliarese (2008), live far from nature and natural consciousness. Nature consciousness should be gained through the use of natural elements and spaces in the child’s living environment (Köşker, 2019, 295). In addition, risk perceptions should be developed within acceptable limits in order for children to get to know their environment. “Perception of risk is the process of making sense of the complex world in order to choose and act (Saari, 2000, 455). However, due to the current pandemic conditions, we cannot talk about a healthy urban outdoor use.

Schools have become much more important for pre-school children, who are provided with the necessary hygiene conditions to continue their school. Schools have now become almost the only place where children can meet their socialization needs. There are many studies on the importance of school outdoor use. Considering that children’s outdoor use is only and/or largely limited to the use of school outdoor spaces in today’s pandemic conditions, the value of school gardens has increased significantly.

Today’s school gardens are generally designed as “…cold and monotonous surfaces covered with concrete or asphalt material” (Özdemir, 2019, 384). In order to talk about a school garden that will meet the developmental needs of children correctly and adequately, a correct school garden design must be made. School gardens, where natural and artificial elements are used in the right proportions, offer the ideal environment for the development of children.

According to Piaget, the human mind develops in four stages. It is not possible to move on to the next stage until one stage is completed. Preschool children are in the 2-7 age group, which Piaget defines as the ‘pre-operational period’ due to their age. Schools should have physical and social equipment that will support the development of children in this age period and meet the needs of students. Children whose needs are satisfied in the school environment like their school more. For children who love their school, there is a positive school climate in that school.

Churchman (2003) emphasized that he did his work on children because the needs of children were considered the least in urban designs (Churchman, 2003, 99). Within the scope of this study, the needs of preschool children, the activities they do to meet these needs, and the physical characteristics of the outdoor spaces where they do these activities will be examined. The obtained data will be associated with the school climate perceptions of the children.

1.1. **Aim**

Outdoor use is very important in the physical, social and cognitive development of children. In today's pandemic conditions, outdoor use of children has been greatly limited. Especially during the time that kindergarten students can attend school, outdoor use has become almost limited with the use of school outdoor spaces. The aim of this study is to determine the effect of kindergarten students' outdoor use of school on their perceptions of school climate during the epidemic. Thus, by drawing attention to the importance of school outdoor use, future school outdoor designs will be shed light on.

1.2. **Scope**

For children whose outdoor use is very limited during the pandemic process, using school open spaces will contribute to their development in many ways. In this context, the study was carried out at a Kindergarten, during the pandemic period (2021), when schools were open.

2. **METHOD**

A descriptive research method was used in the study. First of all, the needs of preschool children were determined by scanning the literature. The relationship between the identified needs and the concepts of activity and space has been established. Then, the findings obtained from the students were added to the study. "Researching with young children is a complex task (Graue and Walsh, 1998, 13)". It is necessary to create a good study plan. For this reason, a single data source was not used in the study, the study was carried out both with verbal data obtained from children and with pictures made by children.

2.1. **Limitations of the Research**

Bringing together the concepts of 'school climate' and 'outdoor use', this study is located at the intersection of Educational Sciences and Landscape Architecture. School outdoor use is very important for children of all age groups. However, the development levels and needs of children in different age groups are also different. For this reason, the different outdoor needs of children in different age groups should be determined by separate studies. Within the scope of this study, the outdoor use of kindergarten students was examined.

In order to determine the outdoor use of children, the school where the study will be conducted should have a garden. In addition, the school administration should adopt an attitude that supports school outdoor use. In order for the school outdoor space to be used effectively by the school administration, parents should also support the school outdoor use. "Parent education can be provided with the support of the Ministry of National Education, Ministry of Health and media institutions, and the necessity of outdoor games in different weather conditions and the importance of natural environments can be explained (Çetken &Çelik, 2018, 334-335)". In addition, in order for the study to be carried out, a program supporting the physical activities of the students must be carried out at the school where the study will be conducted. Another limiting factor in conducting the study is the necessity of not interacting with students from outside the school due to the pandemic conditions.

In the context of these restrictions; The Kindergarten, which has a school garden, parents support outdoor use, the school administration attaches importance to outdoor use and the school administration supports this study, has been determined as the study area.

2.2. **The Problem of the Research**

Outdoor use is very important for the development of children. Urban open and green spaces are an environment where children get to know the outside world, especially for children living in the city. In this environment, children meet many needs that they need to meet in order to be a healthy individual. Although outdoor use is so important, children cannot use outdoor spaces for a long time due to some limitations brought by urban life. The most important of these limiters is the security problem and the lack of sufficient time. Children need a senior with them for outdoor experiences. In today's conditions, an epidemic disease factor has been added to these limiters. The epidemic, which affects us on a global scale, has almost destroyed the outdoor use of children. Kindergartens, where education continues by taking the necessary health precautions, have become almost the only place where children can meet their psychological and physical needs -after their homes-. Some of the measures taken in schools due to the pandemic are the constant ventilation of indoor spaces and the gathering of as few people as possible. Kindergarten students who are in the age of play need to spend time with their friends. School open spaces are areas where children can spend a healthy and safe time. Children now have to meet their needs in urban open and green spaces, in the open spaces of their schools. For this reason, the importance of school open spaces has greatly increased. With the correct use of school open spaces, a positive school climate perception can be created for children at school.

2.2.1. **Sub-problems of the research**

The development of children can be supported in many ways with the use of school open spaces. However, the important thing is that children not only use the school outdoor space, but also that the activities they do support the development level they are in due to their age. In addition, in order to talk about a healthy and long-term outdoor use in kindergartens, the school garden must have an appropriate landscape design. All these factors are effective in children's perception of school climate. Learning the thoughts of children in the landscape design of school gardens is of great importance in terms of designing suitable for them. In this context, it should be determined which spatial characteristics the kindergarten gardens should be parallel with the children's thoughts-.

2.3. **Research hypotheses**

The outdoor use of kindergarten students, whose outdoor use is greatly restricted during the pandemic process, positively affects their school climate perceptions.

The number of activities performed by the kindergarten student who spends enough time outside of the school increases, and accordingly, the chance of each child to perform and/or choose the activity appropriate for his/her own development level increases.

3. **THEORETICAL FRAMEWORK**

3.1. **Preschool Children's Needs**

Preschool children are in what Piaget calls the 'pre-operational period' due to their age. "The most important features of the preoperational period are children's egocentrism - a young child's inability to see things through another person's eyes (Gerrig & Zimbargo, 2012, 307) and centering - children's tendency to concentrate on only one aspect of a situation and ignore other relevant aspects (Gerrig & Zimbargo, 2012, 307)". According to Piaget, the mind develops in four stages in the preoperational period which covers the 2-7 age group. In order to move on to the next period, the current period must be completed. This is possible by meeting the needs of the current period.

Schools have many duties and the most obvious duty is to provide education. In addition, socialization, transferring social values and ideas, and preparing children for adulthood are among their other duties (Martin, 2006, 92). Schools fulfill these duties by meeting the needs of children. Children whose needs are met are happy. "For children to enjoy life, all their physical, emotional, social and cognitive needs must be met and their full potential must be developed (Pringle, 1986: 20)". Children living in the city spend most of their time in schools. Especially during the pandemic process, schools are of vital importance for children to meet the above-mentioned needs.

In this context, the physical, emotional, social and cognitive needs of preschool children will be explained.

3.1.1. ***Physical Needs of Preschool Children***

Children want to move. Moving enables children to explore both their muscle development and the outside world. “Many health professionals see a link between the decline in active outdoor play and the rise in childhood obesity. A typical schoolaged child today spends four to six hours with high-tech media, most of it indoors, and less than one hour outdoors in non-sports activities (Miller and Almon, 2009, 47)”. Sports activities are not only important for the physical health of children, but also for their socialization. Thanks to sports, the child feels that he belongs to the environment he is in, understands the importance of teamwork, and realizes that the concepts of winning and losing in life take place as a whole.

Doctors warn that “Because of obesity-related problems such as high blood pressure and diabetes, doctors now warn that today’s children may be the first generation in 200 years to have a shorter lifespan than their parents (Miller and Almon, 2009, 47)”

3.1.2. ***Emotional Needs of Preschool Children***

Healthy emotional development occurs when the teacher prepares opportunities that do not cause the child to get bored and angry in a comfortable and safe learning-teaching atmosphere (Senemoğlu, 1994, 23). This is possible in schools where the school climate is perceived positively by children. The school climate perception of the child, who has the opportunity to express his feelings at school, is also positive. It is possible for children to meet many needs with games. Play allows children to express their emotions and improves their ability to cope with different emotions. ‘While children have the opportunity to express their negative feelings in the play environment, they often provide relief by getting rid of these negativities (Koçyiğit, Tuğluk & Kök, 2007, 336).

3.1.3. ***Social Needs of Preschool Children***

“…While social skills enable children to socialize, they also enable the society they live in to continue in a healthy way (Akbaş, 2019, 26). There are many social situations that young people have to deal with: asking for help, offering help, being able to say ‘no’, wanting to be informed, wanting to join a community (Spence, 2003, 85). They are the first social circle houses for children. For most children, kindergartens are at the forefront of the places where they enter the circle of friends and establish friendship bonds. ‘Play’ is one of the best tools for children of their age to learn to be part of a community in their school. Although games that require cooperation and social interaction can be played indoors, the outdoor space is very important in meeting the social needs of children in terms of both the freedom of movement it provides and the diversity of games. School gardens designed according to certain Landscape Design criteria are among the outdoor spaces where children can develop their social skills safely.

3.1.4. *Mental Needs of Preschool Children*

Kindergartens develop the mental abilities of children. Playing games is an important activity for the mental development of children. “Outdoor games are important for children’s development areas and for them to be healthy individuals (Çetken & Çelik, 2019, 334)”. Exterior, with the possibilities provided, provides diversification of children’s games and activities. This diversity positively affects the mental development of children.

In children, the reduction of the outdoor use rate (pandemia, security, time ... etc) may cause children to reduce the efficacy and immobilization of children. This decline may cause some health problems and /or increase the degree of the experiencing ones. “Another illness that is on the rise among children is mental illness. There is no study showing that this increase is directly related to the decrease in gaming. However, it is known that play is important for child development socially and emotionally and has an important role in reducing stress (Miller & Almon, 2009, 47).

Within the scope of this study, physical, emotional, social and mental needs of preschool children were examined. The relationships between these needs and -activity, school open places and school climate- has been established.

Activity

For many people, play is a physical activity where you sweat and get rid of excess energy. This is a very simple view, the game has much more important aspects on child development (Bell, 1997, 85). In preschool children, play is extremely important in terms of all developmental characteristics (Ayan & Memiş, 2021, 147). Play is a tool for children to express themselves and learn about the world. “Play in a healthy kindergarten does not mean ‘nothing’. The game does not turn into chaos, it is not shaped by the dominance of adults. Children develop their own initiative and discovery skills (Miller and Almon 2009: 12)”. Play does not only contribute to the development of the child, but also has an educational value (Akbaş, 2019, 26). “Play, which is a natural learning environment for children, can be used by integrating it with activities to develop social skills (Durualp & Aral, 2010, 169)". Games played within the scope of certain rules help children to understand the limits of their own freedom by respecting everyone's rights.

Within the scope of this study, the 'playing game' activity that children do to meet their needs was examined.

School Open Spaces

School open spaces are not just places where children socialize and play. School open spaces are a small-scale reflection of the outside world. In their study, Malberg and Karen (2018) found that students interact with their friends in the schoolyard in various ways, get to know themselves better and improve their interpersonal relationships, thus increasing their own well-being (Malberg and Karen, 2018: 18).

The place where children feel the safest is their 'home'. The 'house' is a shelter with four walls that protects children from both climatic conditions and harmful social environments. It is not possible for children to fully learn about 'life' in this sheltered structure. The other architectural unit that teaches children that there is a place where they can feel safe outside their home is the 'school'. As children get older, their range of motion expands. Thus, the necessity of going out of the architectural structure whose boundaries are clear shows itself. The sheltered structure of the interior, the limited activity and the inadequacy of movement make the use of the outdoor space necessary. A relatively sheltered (simple home accident) interior cannot prepare a child for life dangers. The concept of 'stranger' is just a 'word' for a child who does not use the outdoors. For the child who does not meet animals such as insects and worms indoors, these animals remain as imaginary beings only in stories. In the later years of life, these imaginary beings may turn into an element of fear with the delusion because of not having met them before.

Outdoors means freedom of movement for children. Activities such as running, rolling, etc. can cause minor injuries. Thus, children learn to protect themselves.

The concept that shows how satisfying all these outdoor activities are for children is 'belonging'. "The concept of place emphasizes the importance of feeling belonging and establishing emotional bonds (Carmona, et al. 2003: 97)". The child's feeling of belonging to the environment he/she is in is an indication that he/she likes that place and that the outdoor space meets the child's psychological needs. "If there is a relationship between evaluating a place and being satisfied with that place, this relationship depends on the individual characteristics of the person evaluating the place (Canter, 1977, 107).” Children evaluate their environment according to their age in their own perception systems. If the physical environment meets the needs of the children, the children love it, they feel they belong there.

There have been many studies showing that green spaces have positive contributions to children’s cognitive, social and emotional development (Taylor & Kua, 2006, 126). Today, hard ground is generally dominant in school gardens. It is not possible for most school gardens to talk about an effective landscape design.

It is wrong to evaluate school gardens only according to their physical characteristics. The real environment is the ‘social environment’. The physical environment is under the social environment and it is not possible to separate these two concepts from each other with clear boundaries.

Within the scope of this study, the garden of a Kindergarten was examined.

School climate

“A school’s climate is its atmosphere for learning. It includes the feelings people have about school and whether it is a place where learning can occur. A positive climate makes a school a place where both staff and students want to spend a substantial portion of their time; it is a good place to be (Howard, Howell & Brainard 1987, 5)”.

School climate has four dimensions: physical and socio-emotional safety, teaching and learning quality, interpersonal relationship and cooperation, and the structural environment (Cohen, McCabe, Michelli & Pickeral, 2009, 184). Within the scope of this study, the interpersonal relationship – cooperation and structural environment dimensions of the school climate will be examined.

Interpersonal relationship-cooperation in School Climate is associated with emotional, social, and mental needs.

In the school climate, Structural environment is related to physical needs. The physical environment and the social environment cannot be separated from each other. For this reason, within the scope of the study, the physical and social dimensions of the school outdoor space were examined together.

In this study, ‘Interpersonal relationship - cooperation’ and ‘Structural environment’ dimensions of school climate were examined. The work plan is as follows:

Table 1.

The work plan of the study

Needs	Activity	Place	School climate dimensions
Physical Emotional Social Mental	Game	School garden	Interpersonal relationship and cooperation Structural environment

3.2. **Stages of the Study**

The study plan with the Kindergarten students is as follows:

In Stage 1, the Kindergarten students were asked about the games they like to play the most in their school. The aim here is to evaluate the variety of activities and to determine whether the activities are indoor and/or outdoor activities.

In Stage 2, the children were asked to draw a picture of their favorite place at school. At this stage, the aim is to determine the spatial preferences of children at school. The place where children paint will actually be the place that best meets their developmental needs. The better the children can meet their needs in a place, the more they like that place. Pictures; interior description-outdoor description will be evaluated according to their existence.

In Stage 3, the children were asked to draw a picture of their dream school. The purpose of this section is to determine which types of spaces children feel lacking in school. In addition, it is aimed to determine which activities children want to do at school (games that the school cannot play due to physical deficiencies). Determination of working stages are as follows:

Table 2.

Determination of Working Stages

			Purpose	Evaluation
Stage 1	Asking the students about the 3 games they like to play the most at school.	Determining the variety of activities in the school. Determining the spatial preferences of children	Is the variety of activities in the school sufficient?	

Stage 2	Asking students to draw a picture of their favorite place at school	Determining the spatial preferences of the children.	The place where children paint will be the place that best meets their physical and social environmental needs.
Stage 3	Asking students to paint the school of their dreams.	Determining the physical environment deficiencies of the school for children	It will be determined what type of space (indoor/outdoor) the children lack in the school.
Evaluation	Examination of children’s pictures according to the presence of outdoor		

The relationship between “study stages” and “study plan” is as follows:

Table 3.

Adding the Data to be Obtained from the Study Stages to the Study Plan

<table>
<tr><th>Need</th><th>Activity</th><th>Place</th><th>School climate dimensions</th><th>Data to be obtained from Stage 1</th><th>Data to be obtained from Stage 2</th><th>Data to be obtained from Stage 3</th><th>Conclusion</th></tr>
<tr><td>Physical</td><td rowspan="4">Game</td><td rowspan="4">School yard</td><td rowspan="2">Interpersonal relationship and cooperation</td><td rowspan="2">Is the variety of activities at school sufficient for the development of children?</td><td rowspan="2"></td><td rowspan="4">Which space (indoor-outdoor) is insufficient to meet the needs of children?</td><td rowspan="4"></td></tr>
<tr><td>Emotional</td></tr>
<tr><td>Social</td><td rowspan="2">Structural environment</td><td rowspan="2"></td><td rowspan="2">Is outdoor use of children sufficient?</td></tr>
<tr><td>Mental</td></tr>
<tr><td></td><td>Data will be obtained from Stage 1</td><td>Data will be obtained from Stage 2</td><td>Data will be obtained from Stages 1 and 2</td><td></td><td></td><td>Data will be obtained from Stage 3</td><td>What are the children’s perceptions of the school climate?</td></tr>
</table>

4. FINDINGS

The study was conducted with 53 students at a Kindergarten. 6 students are 3 years old, 18 students are 4 years old and 29 students are 5 years old. Data obtained from the students are as follows:

Table 4.

Adding the Data Obtained from the Students to the Study Stages Table

		Purpose	Evaluation
Stage 1	Asking the students about the 3 games they like to play the most at school.	Determining the variety of activities in the school. Determining children's spatial preferences	Children mentioned 32 kinds of activities. Even if they are the same age, the variety of activities is a positive feature for children who may be at different developmental levels. Except for games that require physical effort, a clear indoor/outdoor distinction cannot be made for other Games.
Stage 2	Asking the students to paint their favorite place in school.	Determining the spatial preferences of the children.	Children mostly painted the school exterior.
Stage 3	Asking the students to paint the school of their dreams.	Determining the physical environment deficiencies of the school for the children.	The children painted both indoor and outdoor spaces equally. There is no obvious lack of space.
The result of the study	The result of the study is presented in the Conclusion section.		

The working details are as follows:

In Stage 1, students were asked about the games they liked to play the most at school. The diversity of the number of activities is striking in the answers of the children. Children mentioned 32 activities. The needs of the children in relation to these activities are shown below.

Table 5.

Adding the Data Obtained from Stage 1 to the Study Plan

Needs of Children	Activity (Game)
Physical	Freeze game, gymnastics, chair snatch, run, puzzle, hide-and-seek, ballplay, dance, blindfold, racing, high above ground, sport
Emotional	Playing with animals, playing with grass, housekeeping

Social	Games for socialization are not written separately. All the games mentioned are in a quality that will meet the socialization needs of children.
Mental	Chess, mind games, English cards, dough, lego, painting, board toys, playing board games, literacy activity, activity with paper

Games that require physical effort, such as running, swimming, hide-and-seek, playing ball and high off the ground, are played outdoors. In other games, no distinction is made between indoor and outdoor spaces. Depending on the weather conditions, all games can be played outdoors.

In Stage 2, the children were asked to draw a picture of their favorite place at school. At this stage, the aim is to determine the students' space preferences (indoor-outdoor space). The findings are as follows:

Table 6.

Data from Stage 2

Picture of the favorite place in the school	**Number of students painting**
İnterior	21
Pictures with outdoor and/or outdoor and school building	32

While 21 of the students painted the interior of the school as their favorite place, 31 of them painted only the exterior and/or the exterior and the school building. Adding the Data Obtained from Stage 2 to the Study Plan is as follows:

Table 7.

Adding the Data Obtained from Stage 2 to the Study Plan

Needs of Children	**Activity (Game)**	**Place**
Physical	Freeze game, gymnastics, chair snatch, run, puzzle, hide-and-seek, ballplay, dance, blindfold, racing, high above ground, sport	Games that require physical effort, such as running, squat, hide and seek, playing ball and high off the ground, are played outdoors. In other games, no distinction is made between indoor and outdoor spaces. Depending on the weather conditions, all games can be played outdoors.
Emotional	Playing with animals, playing with grass, housekeeping	
Social	Games for socialization are not written separately. All the games mentioned are in a quality that will meet the socialization needs of children.	
Mental	Chess, mind games, English cards, dough, lego, painting, board toys, playing board games, literacy activity, activity with paper	

Associating the Data Obtained from the 1st and 2nd Stages with the School Climate Dimensions are as follows:

Table 8.

Associating the Data Obtained from the 1st and 2nd Stages with the School Climate Dimensions

<table>
<tr><th>Needs of Children</th><th>Activity (Game)</th><th>Place</th><th>School Climate Dimensions</th></tr>
<tr><td rowspan="2">Physical</td><td rowspan="2">Freeze game, gymnastics, chair snatch, run, puzzle, hide-and-seek, ballplay, dance, blindfold, racing, high above ground, sport</td><td rowspan="6">Games that require physical effort, such as running, squat, hide and seek, playing ball and high off the ground, are played outdoors. In other games, no distinction is made between indoor and outdoor spaces. Depending on the weather conditions, all games can be played outdoors.</td><td>Interpersonal relationship and cooperation</td></tr>
<tr><td rowspan="2">Emotional, Social and Mental games played by students are numerous and students enjoy these activities.</td></tr>
<tr><td>Emotional</td><td>Playing with animals, playing with grass, housekeeping</td></tr>
<tr><td rowspan="2">Social</td><td rowspan="2">Games for socialization are not written separately. All the games mentioned are in a quality that will meet the socialization needs of children.</td><td>Structural environment</td></tr>
<tr><td rowspan="2">Most of the students made outdoor and/or outdoor indoor-related pictures as their favorite place at school.</td></tr>
<tr><td>Mental</td><td>Chess, mind games, English cards, dough, lego, painting, board toys, playing board games, literacy activity, activity with paper</td></tr>
</table>

The physical facilities of the school are important for the physical development of students. Therefore, physical needs are associated with the structural environment, which is one of the dimensions of the school climate, and emotional, social and mental needs are associated with the dimensions of interpersonal relations and cooperation.

In Stage 3, students were asked to paint a picture of their dream school. At this stage, the aim is to determine which space (indoor-outdoor space) the students feel lacking. The results are as follows:

Table 9.

Data from Stage 3

School pictures of students' dreams	Number of students who painted
Interior	27
Pictures that combine outdoor and/or outdoor and school building	26

27 of the students made indoor, 26 outdoor and/or outdoor - indoor pictures. The number of students' outdoor and indoor pictures is very close to each other.

Table 10.

<table>
<tr><th>Needs of Children</th><th>Activity (Game)</th><th>Place</th><th>School Climate Dimensions</th></tr>
<tr><td rowspan="2">Physical</td><td rowspan="2">Freeze game, gymnastics, chair snatch, run, puzzle, hide-and-seek, ballplay, dance, blindfold, racing, high above ground, sport</td><td rowspan="6">Games that require physical effort, such as running, squat, hide and seek, playing ball and high off the ground, are played outdoors. In other games, no distinction is made between indoor and outdoor spaces. Depending on the weather conditions, all games can be played outdoors.</td><td>Interpersonal relationship and cooperation</td></tr>
<tr><td rowspan="2">Emotional, Social and Mental games played by students are related to this part.</td></tr>
<tr><td>Emotional</td><td>Playing with animals, playing with grass, housekeeping</td></tr>
<tr><td rowspan="2">Social</td><td rowspan="2">Games for socialization are not written separately. All the games mentioned are in a quality that will meet the socialization needs of children.</td><td>Structural environment</td></tr>
<tr><td rowspan="2">Most of the students made outdoor and/or outdoor indoor-related pictures as their favorite place at school.
↓
In the school pictures of the students' dreams, a significant number of indoor and outdoor distinctions were not found</td></tr>
<tr><td>Mental</td><td>Chess, mind games, English cards, dough, lego, painting, board toys, playing board games, literacy activity, activity with paper</td></tr>
</table>

Adding the Data Obtained from Stage 3 to the Study Plan

5. DISCUSSION

The importance of outdoor use in the pandemic process (COVID-19) has been better understood. With the implementation of the curfew due to the pandemic, people have experienced great deprivation in their outdoor-related activities. When there was no curfew, the accuracy of existing outdoor designs began to be questioned more. "The pandemic, which has affected the whole world since the beginning of 2020, requires discussing the concept of healthy cities and such issues in the world through urban space (Tunçay & Eşbah, 2020, 59)" Are there enough open spaces in the city, existing open spaces will meet the needs of the user population? Is it of good quality, is there enough green space in the open spaces, is the vegetative arrangement in the green areas done correctly?"... are the first questions that come to mind. It is possible to increase these questions from upper scale plan decisions (creation of green corridor…) to lower scales (locations, sizes, activity diversity of urban parks…). Each question also requires a research specific to that subject. "In order to prevent the spread of the virus and to control the rate of spread, educational institutions were temporarily closed and distance education was started in many educational institutions (Dinçtürk, Dal & Açıksöz, 2020, 793). However, if a curriculum that supports outdoor use was implemented in schools, the number of days when schools are closed could be reduced. For this reason, studies on school open spaces should be diversified at different levels (primary school, secondary school, high school…). Outdoor use should be encouraged in schools. With the Covid-19 pandemic, "The impact of healthy cities and successful public spaces on human health is more talked about than before (Özcü & Atanur, 2020, 249)." Successful public space plans and designs depend on increasing people's relationship with nature as much as possible. Children's relationship with nature should not be limited to city parks but should also be supported by outdoor designs to be made in schools.

6. **CONCLUSION**

It can be said that the outdoor use of the kindergarten students has a positive effect on the school climate perceptions of the students. In the data obtained from Stage 1 (asking children about three games they like to play at school), the qualitative diversity of the games stands out. Considering that each child is special and each child may be at a different developmental stage, it can be said that the activities that are in large numbers support each student's development individually. According to the data obtained from Stage 2 (children were asked to draw a picture of their favorite place at school), children enjoy spending time outside of the school. The loving use of a space is an indication of how high the space meets the user's needs. In addition, the spatial diversity in children's indoor use (gym, swimming pool, toy corner) draws attention. According to data from Stage 3 (children were asked to paint a picture of their dream school), there is no apparent lack of interior or exterior space for children's schools. Children like school indoor and outdoor almost equally. Accordingly, children perceive the indoor and outdoor adequacy of their school equally. Another remarkable point in the study is that 6 students in the age group of 5 draw their own school and/or the emblems of their own school while drawing the school of their dreams; While painting the place he likes most at school, 10 students draw themselves as 'happy' in the picture. These are an indication that children feel fully 'belonging' to their school. In addition, in some of the pictures drawn in the 5-year-old group, the students showed the school of their dreams as 'primary school'. This can be considered as an indication that the school's process of preparing students for the continuation of their education was successful.

Another point that draws attention in the direction of the data obtained is as follows: the number of natural elements (sun, tree, flower, grass, animal, etc.) used by the students in their paintings is quite low. 6 of the students who painted their favorite place at school and 7 of the students who painted their dream school used natural elements. This can be considered as an indication of the lack of natural elements in the school exterior.

In this study the school administration, teachers and parents support outdoor use. In addition, the school's outdoor facilities are large enough to meet the needs of students. For kindergartens, where outdoor use becomes more important during the pandemic process, it is a necessity in today's conditions that kindergartens have a garden of sufficient size and that the garden has a suitable landscape design. Kindergarten gardens, designed in accordance with the needs of children, have a positive effect on children's perceptions of the school climate.

7. RECOMMENDATIONS

The school is obliged to change the behavior of the individual and to bring new behaviors to the individual in order to adapt to the changes in his environment (Şensoy, 2018, 176). In the event of an epidemic on a global scale, schools are effective places for children to adapt to new living conditions, even under conditions of curfew. Due to the limited use of outdoor spaces due to the pandemic, school outdoor spaces are of great importance in providing children with behaviors appropriate to their developmental level. Gaining these behaviors is possible with appropriate spatial designs.

Although the importance of pre-school education is known, it is criticized that a common quality standard cannot be provided in the education process abroad and in Turkey. One of the important problems in the education process is the lack of conditions suitable for the functional diversity required by the education programs (Şahin and Dostoğlu, 2016: 36). Quality in kindergartens from students' point of view; It depends on good relations with other students, choosing what to do and avoiding games in which they sit and remain silent (Einarsdottir, 20056 483). The fact that kindergartens do not have a garden according to certain standards also prevents functional diversity. The fact that kindergartens have a garden is one of the factors that contribute to functional diversity.

There are some factors that limit outdoor use in kindergartens. These; Negative approaches of the school administration and/or teachers to outdoor use, parents' reluctance to use the school outdoor for various reasons (illness, injury, safety…) not arranged in a way to support their development…).

There are many studies showing the positive effects of outdoor use on children's cognitive, physical and emotional development. Considering that children living in an urban environment spend most of their time indoors, it is possible to say that this situation will have a negative impact on their development. By taking necessary precautions, children's outdoor use in schools should be supported with appropriate space designs.

In places where the number of rainy days is high, the use of movable (removable) top covers and flooring material that will not become slippery when wet can increase outdoor use. Wind curtains to be created with appropriate vegetal designs in places with high winds, vegetal designs that will reduce the burning effect of the sun at noon can be given as examples of solutions that support the outdoor use of schools.

There are many studies showing that playing with natural elements (tree, soil, stone, leaf…etc) has a positive effect on children.

Education and learning is an activity that can only be carried out indoors and indoors." Instead of the perception of "integrated with nature and carried out hand in hand", an education approach should be tried to be adopted in a way that will raise awareness from the closest stakeholder to the farthest stakeholder in the society (Arabacı & Çıtak, 2017, 40).

According to Lewis (1972); The human/plant interaction that people make in their own gardens contributes to community commitment, aesthetic pleasure and self-esteem (Kaplan, 1983: 149). According to Munoz (2009), the health of children interacting with nature and using the outdoor space - reducing attention deficit (Munoz, 2009, 6), feeling good (Munoz, 2009: 7), reducing hyperactivity (Munoz, 2009, 9) , anxiety alleviation (Munoz, 2009, 9), alleviation of depression (Munoz, 2009: 9), reduction of childhood obesity (Munoz, 2009, 11), … are affected positively. The child dealing with plants develops a sense of responsibility outdoors, and his awareness of how he should treat living things increases. For this reason, natural spaces should be created in the outdoor designs of schools, and children should be interacted with natural elements as much as possible.

According to researchers in the field of education, environmental awareness and attitudes towards the environment begin in the preschool period. This shows that good environmental habits can be gained to children in this period (Özburak, 2016, 25). Raising an environmentally friendly generation is of vital importance for the future of our world – our future. "Technology or laws alone are not sufficient in solving environmental problems, and the behavior and reactions of the people are also important. The positive impact of this situation depends on the educational activities to be carried out on the environment (Mansuroğlu & Dağ, 2021, 230). There are also studies showing that spending time in natural environments increases the development of environmentally sensitive behaviors and the tendency to protect natural resources (Kaymaz, Baki, Sarıhan, & Perçin, 2019, 200). The most effective environmental education can be made possible by children spending time in a natural environment and/or in an environment where natural elements are predominantly used. “Children’s sense of space occurs at various scales: these child-scale experiences of space occur through activities such as building a castle, climbing trees, or playing with friends (Derr, 2002, 125)”. Increasing the variety of activities in kindergartens can be possible with the use of outdoor.

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CHAPTER 5

ENVIRONMENTALLY FRIENDLY CITY

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INTRODUCTION

The opportunities and potentials offered by the environment are decisive in consumption habits. However, the effect of technology on this process is undeniable, especially cultures in the pre-industrial civilization stage in terms of culture and economy have reached the most advanced level thanks to technology. On the one hand, technology provides unprecedented convenience, on the other hand, it creates a consumption culture that is alienated from nature. This process has started to gain a transnational importance with the phenomenon of globalization.

Crimes in the built environment, which are only a part of environmental problems, have reached dimensions that threaten the present and future of human beings. This process includes not only spatial problems, but also many economic and social problems such as unemployment, poverty, future anxiety and alienation.

In the light of globalization and technological developments, human beings are aware that air, water and soil pollution affect natural vegetation, the health of living species and rural-urban culture. The planning of environmentally friendly living units, which can provide economic continuity with technological analyzes that can provide accurate and precise results, can be achieved with a cultural formation that does not consume environmental values.

In this study, the environmentally friendly planning approach and principles are explained, emphasizing the assumption that the integration of this process with practices that support the evolutionary development of life should be the first target in the fight against environmental crimes. In the study, the literature review method is used and the importance and necessity of consciousness in the built environment are examined in detail within the framework of the concepts of environmental crime, environmentally friendly planning, land speculation and environmental education.

Environmental Crime

Every design, plan and policy that threatens the existence and continuity of living things is an element of crime against the environment. Economic, environmental, legal and administrative unethical attitudes towards living spaces and self-interested housing policies affect the built environment, leading to disintegration in the rural structure, dependent cities and consumed spaces.

Cultural activities are at the forefront of the factors affecting social change. Cultural elements are values, beliefs, symbols, language, norms and habits. The elements of exclusion and acceptance from the cultural elements of the society are important in social change. Changes, developments, modernizations, alienation and corruption in cultural activities can be explained by the relationship of cultural resources of societies with legal instruments and the physical environment, technology and other factors that regulate this relationship (Turhan, 1969: 39). Cultural factors reflect the society's way of life, understanding and making sense of nature and its environment.

The roots of the theories that establish a relationship between the environment and social change are quite old. Those who deal with astrology for thousands of years have searched for a relationship between the events in the sky and social events. Montesquieu stated that the habits, sensitivities and behaviors of individuals are shaped by the conditions of the built environment. The heterogeneous built environment emerges as a fundamental factor in the cultural changes of societies (Bozkurt, 2008).

An economic development at the rate offered by geographical opportunities gains value directly with the distribution of natural resources in the built environment and differentiates the society economically. Demographic structure and cultural formations that change in parallel with economic development affect the general laws of society, in other words, its culture. The built environment factor is an important factor in the consumption habits of societies (Bozkurt, 2008).

Land speculation is an "unearned", "non-labor", "gratuitous" and "unfair" value arising from private ownership and the scarcity of land (Keleş, 2004: 603-604). This value is formed as a surplus income based on the monopoly that the landlord establishes on the land without any effort (Kartal, 1977: 25). Literally, speculation means profiteering, an order established to make excessive profits by taking advantage of scarcity.

"Profiteering on urban land is seen as a natural consequence of the high level of urban land rents" (Keleş et al., 1999: 44). Urban land speculation is the situation in which individuals keep the land they hold, reap more shares than they are or buy land for this purpose in order to benefit from future value increases. This situation prevents the planned growth of cities and therefore adversely affects the urban planning process, which is the main tool of regular urbanization.

The fact that the urban planning process cannot function regularly leads to the unhealthy and irregular development of cities. One of the main causes of distorted urbanization is land speculation. Because land speculation affects the settlement decisions in the city and prevents the development directions, housing densities and transportation levels from being planned (Kılınçaslan, 2010: 191).

Keeping vacant land in the city in anticipation of more land use reduces the impact of urban services and makes it difficult for urban services to choose a location in the city (Kılınçaslan, 2010: 191). On the other hand, new settlements are emerging widely on cheap land around the city. The fact that many urban services cannot be found in the city due to profiteering can cause cities to grow by leaping. Thus, speculation leads to an unnecessary spatial expansion of the city and the rapid disappearance of environmental values.

The fact that the land is kept empty in the city and their high value causes the formation of new residential neighborhoods on cheap land in the widespread area around the city while empty plots in the city stop. This makes it very expensive to cover urban services. Speculation is not just about vacant lots. In the neighborhoods where the land on which buildings have been built, the growth of the city and the permission to increase the density under the influence of political pressures cause the existing buildings to be demolished before the end of their useful life.

In existing settlement areas, speculative gains can be obtained by creating an increase in value through conversion to new forms of use or increase in floor height (Keleş, 2004: 602-604, Ertürk, 1995: 167). In addition, these density increases, which occur without providing urban and vital needs in accordance with the standards, lead to the formation of low living standards in housing areas (Tekeli, 2010: 28-29). The existence of private ownership in urban land gives rise to parcellation. Since the areas between the buildings cannot integrate, the common areas cannot develop and small spaces that do not work are born. Since the parcellation arising from speculation and private property brings a separate structure scheme, the use of money, materials and technical power is under irrational conditions, and compliance with the standards specified in the legislation in the relationship between the use of green space and population is ignored (Tekeli, 2010: 28-29).

Due to speculation, many plots of land in the city are either kept empty or cannot find buyers due to high prices. Interest groups gain unfair gains through speculation, which leads to injustices in income distribution. However, land owners gain an unfair gain by causing construction in areas that need to be protected naturally and historically, such as coastal and forest areas with high rents (yields) on the built periphery (Keleş, 2004: 603, Kartal, 1977: 24).

The fact that land speculation can arise is due to the fact that the land is an immovable resource and the expectation and news of future investments around the land automatically create an increase in value. For example, news of public investment such as bridge construction, road widening or the construction of a large park accelerates speculative activities. The land owner provides a return to himself through natural resources without making any effort and without taking risks (Kılınçaslan, 2010: 191). In fast-growing cities, the value increases in land and land prices are also fast. This process is used by some people to make a profit.

There are interest groups that constantly make land speculation as a business, and these people are the people or people who are known as land owners and take this business as a profession. By purchasing land in urban development areas, they are forcing the cities to expand unnecessarily. Such speculation is called active speculation. On the other hand, there are people who invest their money in real estate for investment purposes and want to make a profit on it. These are people who do the job more passively and do not do it with a strong motive like active speculators. These people are called passive speculators. Since passive speculation approaches active speculation in terms of its consequences and its effect on public interest, it can be said that there is a degree distinction between them rather than a content distinction (Keleş, 2004: 604).

Today, the concepts of rent and land speculation are used in the same sense and are defined as an unfair gain that occurs in the value of immovable property and is earned without relying on labor (Yurtsever, 2010: 385-387). In urban lands subject to ownership, development plans or planning impose various restrictions on the landowner's right of use.

Planning can be used to prevent or minimize rents on urban lands and to ensure that they are brought to the public (Keleş et al., 1999: 63). In a system where private property exists, the creation of absolute rents resulting from scarcity by plan decisions is an inevitable consequence. However, due to planning ethics and purpose, the planning process has to be objective.

In the planning process, it is necessary to predict the development directions of the cities very well and to take into account the property situation. Otherwise, frequent plan changes prepare the appropriate environment by encouraging speculative activities and become a tool in the creation of land speculation (Keleş et al., 1999: 63).

Environmental crime is a product of the human ego to dominate nature. Changing the natural order and balance with wrong land use decisions, inability to renew themselves and/or not to use them effectively and efficiently leads to dependent economy and therefore dependent urbanization. In this process, the natural environment alienates and marginalizes the cultures that have disappeared under the shadow of urbanization.

The impact and contribution of the natural environment, which is the basis for the emergence of life, to biological evolution is a factor that must be protected on a global scale for the continuity and continuity of humanity's existence. In order for humanity to survive within the biological evolution mechanism, ecosystems must be protected by taking into account the complex relationship networks. Natural history proves that it is not possible to recover the ecosystems that humanity has and the other living things with which it is in constant interaction. The evolutionary processes offered by the natural environment for the sustainability of life are changing day by day with the increasing technological developments and scientific researches (Alpagut, 1997: 114-119).

Environmentally Friendly Planning

Cities are one of the most important achievements of humanity. People have shown both social and economic progress thanks to cities. Many civilizations started with the core of the city, grew and developed.

Migration from rural to urban continues to increase in recent years. For this reason, cities are faced with the problems brought about by rapid urbanization. An evaluation with current figures to sum up, the urban population, which reached 50,1% in 2007, reached 54,8% in 2018. This increase will it is expected to continue in the years to come. In the 1950-2050 period the variation of urban and rural population ratios in the world is shown in Figure 1 (World Urbanization Prospects, 2018 transmitting Akçakaya, 2019).

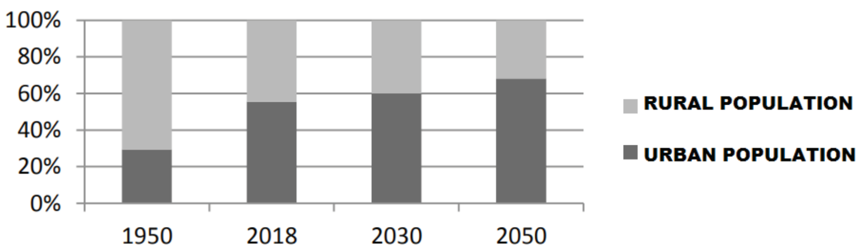

Figure 1. Rural and Urban Population Rates in the World (1950-2050).

Cities with increasing populations cause environmental pollution, CO_2 and other harmful gases and organic and it has turned into places where inorganic wastes are widespread. Urbanization rate due to hyper-urbanization, with the increase above the 70% limit by 2050 it is predicted that environmental problems will increase exponentially (Caprotti, 2015: 5; Łobejko, 2015: 13 transmitting Akçakaya, 2019).

In parallel with industrialization and economic development, the vital and urban needs of the rapidly increasing population are also increasing.

In cities that do not have sufficient social, economic, administrative and technical knowledge to meet the needs of the increasing population, many problems arise with the increasing population (Mengi and Meydan Yıldız, 2019: 185-186).

At the core of planning are urban and environmental development decisions made to provide public interest. However, rent and environmental exploitation arising from private property monopoly are an inevitable result in capital-oriented cities (Keleş et al., 1999; Yurtsever, 2010: 385-399; Meydan Yıldız, 2021a: 609-612). In this process, planning and zoning decisions should be developed with an environmental focus and the participation of the public in the planning process should be increased. Thus, creating new winners and losers in the city can be prevented through services and activities created by plan decisions (Cambell and Marshall, 2000: 297; Meydan Yıldız, 2021a: 629).

Planning is to ensure that every individual in the city can benefit equally from urban and vital services. Planning; It consists of decisions taken to minimize all problems that create social, cultural, spatial injustice and inequality (Meydan Yıldız, 2021a: 610-615). Thus, planning is an objective used to discourage land speculation. However, the planning should be created with environmentally friendly approaches and the citizens should take care of natural resources with the awareness of protection and non-consumption. Otherwise, individual interests and ambitions may cause planning and zoning decisions to become a tool that encourages speculative activities (Meydan Yıldız, 2016).

The city is a common living space where social, economic, political, social, behavioral, technical and scientific changes are experienced with the effect of natural population growth and migration. Therefore, population and changes cause increases in urban and vital needs. Speculative activities in decisions for urban growth threaten the interests of society and cause many problems.

Urban needs choose a place in existing urban lands or in lands that will be added to the city. The land owner's allocation of more shares than the existing land in order to generate extra income and/or keeping the land empty may cause urban growth by spreading or leaping, wasting the scarce land (Tekeli, 2009; Meydan Yıldız, 2018: 32-35). In a city that grows rapidly by intensifying or spreading, consumption processes develop without environmental awareness. The unplanned and nature-exploiting nature of this development becomes even more important for the ecological region that needs to be protected at a global level (Kılınçaslan, 2010: 86-90).

The term consciousness, which expresses the change in time, is used to indicate the common features of the countries that are the most advanced in technological, political, economic and social structure according to the understanding of the past generation, and the technological, political, economic and social structure that countries want to reach is indicated with awareness (Erdönmez, 1993: 12).

Conscious cities are defined as cities that experience technological developments at the highest level, exceed the level of industrialization and reach a post-industrial cultural structure. This type of classification offers an opportunity to classify an urbanization process that has completed industrialization and now returns to post-industrial urban life, away from subjective and ideological judgments. However, limiting urban consciousness to industry and post-industrial life may lead to false conclusions. Therefore, it would be correct to define the concept of consciousness with contemporary urban life (Erdönmez, 1993: 12).

Contemporary urban life, high quality education, quality health services, international prestige in scientific and artistic activities, high level of communication-communication, freedom of expression and belief, economic prosperity, effective and efficient use of resources, a healthy social environment, use of quality water and air defines a lifestyle that respects nature without breaking away from nature (Keleş, 2004). It is also a correct definition for cities with a democratic, participatory and environmentalist legal infrastructure. Otherwise, advanced technology and urbanization that feels strong against nature with technological advances and exploits and consumes scarce resources on a macro scale for profit is not modernity.

Contemporary people, on the other hand, are people who have adopted educational policies for the environment and have made it a way of behavior. To put it more clearly, modern man has made it a way of life to protect and use the natural and historical environment with the principle of public interest, respectful to the soil and all the possibilities offered by the soil with scientific realities, acting by thinking about all living and non-living beings in the ecosystem, using technology and nature as a priority. is an individual who follows with admiration and adopts the dimension that serves social values.

In the historical perspective, the pressure of human beings on ecosystems is increasing with technological development and industrialization. Ignoring environmental awareness in land use decisions causes the natural environment to gradually disappear and economic resources to lose their regenerative power.

Cities pollute their environment, disrupt natural balances, destroy natural values, etc. New searches have started in the face of situations. The development and dissemination of ecology has been effective in the development of the concept of environmentally friendly city. Ecological approaches developed against the modern cities of the industrial age foresee the planning of the city by taking into account the ecological values. The need for a healthy, breathable, green city, intertwined with clean nature, has developed instead of preventing environmental pollution and limiting the destruction of nature, instead of dirty and isolated cities (Meydan Yıldız, 2016).

Policies that can make this process effective are the integration of environmentally friendly planning with the principles of sustainable development (Meydan Yıldız, 2021b: 244). The environmentally friendly planning process is not much different from the classical planning approach; There are the principles of participation, democracy, environment and urban awareness, which are essential to be followed in the process.

In environmentally friendly planning, it is necessary for the public to gain bio education and biotechnological awareness. Thus, in order for the planning activity to become functional, it is inevitable for other disciplines to develop nature-oriented and produce policies. Thus, the citizen, who is aware that he has a voice as an individual against the city and nature he lives in, will be able to follow the plan decisions and the planning process, integrate the planning principles with environmentally friendly processes and prevent the land speculation that provides unfair profits.

Expected features from an environmentally friendly city (Meydan Yıldız, 2016: 40-45):

- planning of cities as natural cities,
- adapting it to the climate and the environment,
- conservation of flora and fauna,
- prevention of water, air and soil pollution,
- reducing greenhouse gas emissions,
- reducing fossil energy use,
- the use of natural energy in urban heating, cooling, transportation and electricity generation in industry,
- implementation of ecological architecture,
- dissemination of clean and ecological transportation systems,
- producing solutions for pedestrian and bicycle-oriented public transportation,
- garbage recycling,

- minimal consumption,
- a simple urban design that is not dense,
- developing rural policies,
- environmental education etc.

Environmental Awareness and Education

In environmental education, it is necessary for the person to re-understand the natural and artificial environment, internalize the need to protect it, and transform the importance of using it without destroying it into behavior. It is imperative that the natural and historical environment exploited by personal interests and the cities that have become concrete and unlivable in this process, to produce permanent solutions with social, economic, political and participatory democratic methods (Türküm, 1998: 172).

At this stage, environmental education should include strategies and policies for problem solving. Instead of making individuals adopt certain ideologies, it is necessary for the individual to think about the importance of scarce resources independently, to transfer them to his/her life and to realize the balance of protection and use.

In this process, the most effective way of socially acquiring environmental awareness is undoubtedly education. Environmental awareness has intellectual, emotional and behavioral dimensions. In other words, environmental awareness; It consists of thoughts that include decisions, principles, comments about the environment, behaviors that are the transfer of these thoughts to life, and various feelings related to all these. The development of such a comprehensive concept, of course, does not occur with a simple process.

This process, which gains momentum as human beings interact with their environment, continues throughout life (Türküm, 1998: 172). The main purpose of environmental education is to oppose wrong conditioning, to create an inquiring, conscious and thinking society and to transfer the biological evolution mechanisms and the continuity of this process to the individual. In this process, collective learning and public participation gain importance (Alpagut, 1997: 114-119; Geray, 1997).

Depending on the globalization policies, making cities safer, healthier, more livable, more equitable, sustainability and efficient use of scarce resources, and therefore environmental awareness has become an international development policy. The misuse of economic resources, therefore the values called environment, under the pressure of the increasing population, and the individual benefit leaving the public interest understanding in the background cause the environment to be polluted, deteriorated or even destroyed. Environmental education can improve the environmental awareness of individuals through the transfer of scientific and cultural knowledge.

However, the main purpose is to protect and improve the environment by ensuring the participation of the public in environmental decisions. This purpose coincides with the function of education, which is to change/improve the social, natural and artificial environment. However, studies show that the scientific and cultural information transfer function of education carries weight instead of this function in the education system in our country. Moreover, it is argued that our education system is in a structure that instills absolute obedience and expects them to fully comply with the norms of thought and behavior it prescribes (Kayıkçı, 2013).

Environmental awareness can be created by providing awareness of the direct connection of every living thing with human beings. For the development of environmental awareness, first of all, it is necessary to demonstrate with scientific evidence that nature and a balance existing in nature and their importance, and then the necessity of protecting and developing them in order to survive. In order to reach this consciousness; It is necessary to realize that the balance of nature is in danger of being destroyed by human interventions consciously or unconsciously (Türk, 2011:134-135).

Ideas, thoughts and messages conveyed in order to provide the appropriate environment, models and practices that will enable individuals to develop a positive attitude towards the environment; it should not be tried to be given in the form of propaganda, imposition and dictation, but should be presented with examples. Repetitions should be made at appropriate frequencies over time and especially the education processes of new generations should be aimed at raising awareness about the environment. This process can only be brought to life with the development of an environment- and living-centered culture (Türk, 2011:134-135).

Environmental awareness is the process of developing value judgments, knowledge and skills for the protection of the environment, displaying environmentally friendly behaviors and seeing the results of these. Environmental awareness is a culture that should be acquired at an early age. Because the interests and attitudes formed in pre-school and school ages form the basis of the desired behaviors in the future.

Value judgments and attitudes formed especially in childhood and young ages are very important in the development of empathy and love for nature in relations with nature at an early age. Their formation means showing environmentally friendly behaviors for the protection of the environment. These developmental stages will be the learning in the affective field that should be taken into account and that will later help the development of environmentally beneficial conscious behaviors in individuals (Erten, 2006).

Consumption Culture and Environment

As a word meaning, the concept of consumption includes the meanings of destroying, spending, squandering, ending, and it has turned into ideology, superiority myth, hierarchical criterion and class representation tool with capitalism (Aytaç, 2006: 28). Consumption culture changes the perspective on urban and environmental values. Cultural alienation is the main source of environmental problems. A formation that negatively affects the biological evolution process directly or indirectly affects the future of life. This relationship is dragged into an even more deadlock by the use of rapidly developing, changing and diversifying technological processes against nature by humans, who are part of nature. However, with the biotechnological changes and developments used in the integrativeness of nature, it may be possible to ensure the sustainability of life by preserving the relationship networks between the natural and artificial environment (Keleş et al., 2010).

Although the understanding of sustainable nature is difficult to implement, it can become a behavior that starts at a young age with a sense of responsibility towards nature. Cultural activities that adopt the relationship between conservation-use and consumption habits suitable for nature can make this process possible (Alpagut, 1997: 114-119).

The survival of countries depends on the economic activities and competitiveness they have gained on a global scale. However, the irresponsible use of macro-scarce natural resources or the lack of renewing time for resources are the biggest obstacles to economic development in the long run. Moreover, it is an important lesson to be learned from natural history that the possible consequences can directly affect ecosystems and lead to the extinction of life on a global scale.

The solution of the consumption culture depends on the policies to be taken on a global scale. Global policies can be achieved through awareness and education at the local level. First of all, local risks should be identified and possible solutions should be supported with environmental education and biotechnological developments.

The understanding of environmental awareness should be assimilated and internalized by states, local governments and citizens (Meydan Yıldız, 2016). The main factor that can make this process effective depends on the adaptation of democratic processes to every economic, political, cultural, environmental and educational process. Environmentally friendly plans can be implemented through effective awareness, a holistic policy and strategic solutions detailed locally (Keleş, 2013: 109-110). The evolutionary processes, which humanity has more and more knowledge on day by day, and most importantly, proved by scientific research -the struggle of life in natural history and the mobility of biological evolution- are a major factor in increasing environmental awareness and awareness (Meydan Yıldız, 2020: 140-143).

CONCLUSION

As social life becomes more complex, environmental problems, which are increasing in number and types, turn into a chain that is difficult to solve. In the light of global processes and technological advances, environmental protection is developing rapidly. Awareness of healthy and orderly urban life for the progress of development within environmental political analyses is also increasing. In this process, the greatest armor in front of the ambition and endless desire for development created by capital is the consciousness of not consuming, which recognizes and loves nature and protects historical and cultural values in the direction of protection and use.

The sense of responsibility of societies towards nature and what is natural for the continuity and continuity of their natural and cultural values is increasing day by day. In this study, social, economic and environmental problems created by planning ethics and aimless actions and land use contrary to the public interest are examined in the context of speculative activities. With holistic and democratic policies in which environmental awareness is internalized, public participation and sensitivity to space use decisions can be ensured.

Depending on the globalization policies, making cities safer, healthier, more livable, more equitable, sustainability and efficient use of scarce resources, and therefore environmental awareness has become an international development policy. Global environmental problems are a reflection of the cultural process and development policies that are disconnected from environmental awareness and consciousness.

Purely economic development policies that do not take into account the natural environment result in natural events becoming a risk that threatens vitality and do not allow natural resources and cycles (such as air, water and carbon cycles) to renew themselves. By adopting the processes and results of biological evolution with awareness raising methods, inferences can be made from the history of nature. Awareness can be created quickly by using mass media through educational programs.

With environmental biotechnology research, issues such as domestic waste treatment, water treatment, industrial waste treatment can be examined and awareness can be created on the availability of biomass energy. In this way, positive effects of pollutants on the environment can be achieved naturally and regularly.

The biological evolution mechanism continues unceasingly, and this process is undoubtedly in a constant change with the relations under the dominance of nature. This change includes humanity, which is a part of the natural environment and an element of this relationship network. The evolution of life continues in relation to changes in the natural environment. Since it is known that the biological evolution mechanism continues uninterruptedly and will continue in the future, we need to know the value of the cultural evolution stage we have reached. Thinking, inquiring and researching, humanity is aware of what is happening in every corner of the world with its rapidly developing technological inventions and mass media. It is imperative to change the consumption habits that disregard nature for the sustainability of life.

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CHAPTER 6

BIOMIMICRY AS AN ARCHITECTURAL DESIGN STIMULI ANIMAL INSPIRED LARGE-SCALE BUILDINGS

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INTRODUCTIOn

Nature has been present in every moment of daily life since ancient times. From then on, the elements of nature were incorporated by human decisions, problems were solved by the inspiration of events in nature. The path to be followed was determined under the guidance of nature. Although, architectural design is evolved under the conditions of nature. Humanity built shelters in trees for protection from weather and animal threats led. Therefore, the need for shelter, which is the fundamental of architectural design, provided the first examples inspired by nature. However, shelters are becoming more and more like today's conditions owing to the developed human skills and the use of raw materials from nature such as clay, stone, ice and straw. Indeed, these two intertwined concepts, nature and architecture, still exist together today even so it is a widely used technique to design a sustainable built environment.

However, with the industrial revolution in 18th century and consumption patterns of humanity led to on an approach away from nature-oriented designs these attitudes caused to resource depletion, environmental pollutions, and climate crisis. Therefore, environmental problems have been incorporated into the understanding of architectural design. Overpopulation and its consequences have led to a rethinking of the scale and orientation of buildings. The most concrete evidence of this is the change in scale of buildings, and vertical alignments and multi-storey buildings are also becoming current. Although, different construction techniques, materials and systems have been invented to meet the new building standards. On the other hand, with these new techniques, natural elements have lost their place in favour of concrete, glass and steel.

Whereas, Large-scale and vertical floor plans were accepted as a solution to overcrowding but did not meet the need for sustainable housing. Furthermore, maintaining the standard of large-scale buildings differs from traditional construction methods. As the size increases, the control mechanisms in the application and design phases of the building diminish. Multi-disciplinary working becomes mandatory to ensure the longevity and sustainability of large-scale buildings while addressing the design features of the building. Architects need lateral design tools to regain control over the entire construction phase. As a result of these issues, new areas have emerged. Such as, software systems and sustainable design methods. The development of computer-aided design gives architects the ability to estimate execution difficulties and potential problems before the construction phase. At the same time opportunity to develop innovative design-thinking methods and to enable the application of free-form design. Despite evolving technology and the diversity of design options, the scope and impact area of structures has increased. For this reason, importance of nature-based design is increased. Göker explains that “humans need to design their lifestyles, businesses, economies, physical structures and technologies in a way that does not destroy their life-support capabilities at the core of nature in order to survive” (Göker, Parisa Göker, Aysun Tuna, & Professor, 2017).

Thus, Biomimicry is a relatively new design method that takes its cue from nature by combining biology and architecture in sustainability manner. Biomimicry systems are based on nature and the imitation of nature’s activities and productions. Therefore, to understand the principles of biomimicry design, should know all the forms, processes, strategies, and principles of nature. As mentioned earlier, evolving technology has not only given architects more control, but also made it easier to understand natural elements to derive designs from. Although, Weinstock estimates that “natural emergence, which describes the way complex natural systems develop, self-organise and grow, contributes to the creation of architectural knowledge for the production of complex architectural and especially performative design.” (Göker et al., 2017).

Considering these points, biomimicry designs are inherently focused on sustainability principles. In view of this, it is important that these principles are put into practise through architectural design. Therefore, this approach should be promoted and reach a wide audience. From top to bottom, from professional designers to students. With this in mind, this article aims to raise awareness of the importance of nature-inspired biomimicry design principles and explore biomimetic design methods to overcome difficulties in Large-scale designs. Animal-inspired examples are selected to limit the scope of the research to the level of organisms. Data collection, classification, SWOT Analysis and comparison methods have been selected to examine the case studies for their sustainability regulations and design criteria. The methodology is to propose a classification study to highlight the biomimicry principles, design features and sustainability characteristics of large-scale animal-inspired buildings.

1.1. Nature’s Importance

Designers are always influenced by their surroundings the culture, living environment, the context can influence and ignite the starting inspirational spark. Therefore, nature and the natural elements are an essential part of human life included from smaller scale to larger scale. Such as, observing a peaceful environment likewise the mountains or the sea, or even petting an animal. Although, elements of nature can use as creating a relaxing atmosphere in design such as plants, natural colours or nature’s itself can be focus point of the design phases.

Nevertheless, the organism living in nature aims at minimal energy consumption, but in the most efficient way, based on the concept of natural selection defined by Charles Darwin. Elements of nature should be competitive, sustainable and durable. Nature is indeed enduring. It contains values that have stood the test of time. These attitudes become the inspiration for designers. Vitruvius values the basic principles of architectural design as firmitas, utilitas and venustas. Similar to nature: be durable, be functional and be designed for a long-term life cycle. Beukers and Hinte estimates that: ‘’There is a duality between technology and nature based on minimal energy consumption. This is because animals and plants, in order to survive in competition with each other, have developed methods to live and reproduce with as few resources as possible’’(Beukers & Hinte, 2005)

Hence, Keleş describes as ‘’nature all that is outside of man; for example, the earth, the mineral resources, the water, the air, the plants and the animals.’’ (Keleş, 2003) Attitudes towards nature influence living standards, daily activities and even health. Under the circumstances of contemporary life spending most of the day into buildings. Also owing to the developed technology, material and structural systems the permanence of existing buildings accordingly their impact on living environments is increased. According to Karahan, long-term buildings consist of 50-99 years. (Karahan, 2010) Considering to the long-life cycle of buildings, living spaces should be both mentally and physically healthy, but also pay equal attention to the environment in which they are located. This must be the most important approach for anyone involved in the cycle of designing or producing spaces.

1.2. Biomimicry and Sustainability

Even though the application of biomimicry design principles is a relatively new method, stimuli from nature have been known since ancient times. B.C 5th – 6th century in Ancient Greek most of the answers tried to give under the light of nature by philosophers which are named as nature philosophers.(Kandiş, 2019) The word biomimicry is a term derived from bios and mimicry, which originated in ancient Greece. Bios: means nature and mimicry means imitation. (Volstad & Boks, 2012) The impact of nature on arts and crafts and, of course, architecture is remarkable. In prehistoric times, elements of nature such as flowers and animals were the main source of inspiration. Such as the appearance of flowers applied as decorations on structural columns, ceilings or gates of the temples. Indeed, nature helps humans with its functions and improves the formation of our aesthetic values through its services. According to Benyus ‘’nature has an instrumental value and is also the first constructor of aesthetic consciousness.’’ (Benyus, 2022)

Nevertheless, since the second half of the 20th century, especially due to increasing pollution and global warming, researches has focused on nature-friendly and sustainable designs. Sustainable designs have adopted these perspectives as concept; dealing with current environmental problems and seeking solutions for the existing and feature living habitats. Feria and Amado estimates that architectural design considers three main areas, economic, social and environmental, in order to be sustainable. (Feria & Amado, 2019) Also, Feria and Amado formulate that the principles of sustainable design include the following.

- Minimisation of resource consumption

- Reducing the need for maintenance

- Recycling of materials at the end of a building's life cycle

- Protection of natural systems and their function in all activities

- Promoting the quality of the built environment

Therefore, despite primeval times, in today's conditions nature was not imitated only visually, due to the developing technology, natural characteristics, functions of animals, ecosystems, plants and humans are adapted and transferred to the design. Even most of the designers believe that a design that conforms to the principles of biomimicry should not only mimic appearance, but also include suggestions for protection against natural disasters, sustainability and protection of nature. Considering this, Biomimicry principles overlap with sustainability in many different areas, such as minimisation of resource consumption, recycling materials, protection of natural systems. Because nature is long-lasting, permeable and strives for less energy, less material and more potential although nature does not create waste; it even transfers one thing to another and has recycling principles.

To sum up the principles of biomimicry were initially sustainable, by mimicking the principles, elements, systems and methods of nature. Likewise, self-cleaning paint inspired by the lotus flower is a good example of the adaptation of natural elements through technological developments, biomimicry principles and sustainability methods. The main purpose of self-cleaning paint is simultaneously avoiding energy and water waste by ensuring the reuse of rainwater as a clean system.

So, Biomimicry has played an important for generations in terms of imitating the elements of natural forms or using the functions of the elements of nature to find solutions to existing problems by sustainable and nature respected methods.

2.LITERATURE REVIEW

2.1. Classification Methods of Biomimicry Principles

Although, many designs promising to sustainable and nature friendly approaches it has been observed many of them still remains at the greenwash level with their few greenery spaces includes to design concepts. Consequently, these approaches there is neither a sustainable nor biomimetic approach.

As a result of this attitudes, understanding the rules of sustainable methods and biomimicry design principles thus transferring correctly to the designs is very important. Therefore, to regards of clarifying the different approaches, principles, levels and dimension of Biomimicry classifications are has an important role. Thus, classification provides to follow a more accurate approach.

Therefore, understanding biomimicry principles and make these principles more widespread different classification methods are developed. Such as Nachtigall made that classification based on fields in 1997, into 3 parts which are structural biomimetics, procedural biomimetics, and informational biomimetics. These approaches also can be described as, imitating constructions and materials from nature, imitating the processes in nature, and based on transferring the natural principles and process. (Nachtigall, 1997) Later in 2004, Ayre articulates that the classification problems of the biomimicry approaches because of the overlapping different categories and offers a new classification method such as, structures and materials, mechanisms and power, behaviour and control, sensors and communication and generation biomimetics. (Ayre, 2004) After these classifications in 2007 the most prevalent approach determined by Biomimicry Guild. These understanding downgraded classification methods into 2 categories such as; Design looking biomimicry and Biology inspired design.(Peters, 2011)

The first approach is Design to Looking Biomimicry approach. Also, express as solution-based approach or the Bottom-up approach. In this approach natural elements gives inspiration as the initiator effect on the design stage. This approach is appropriate for searching to the focus point and considering nature-based elements as solution. Because Garcia etal. articulates that, the design process starts with defining natural elements as a source of inspiration with the expert people from biology or ecology field and then after that designing project continues by adapting the natural elements through design.(Garcia-Holguera, Clark, Sprecher, & Gaskin, 2016)

The second approach is Biology Inspired Design. Although, can referred as problem-based approach or top-down approach. Because this time design starts with a searching solution motivation for a problem encountered. After that nature become solution with an existing problem with its consistent elements, systems, mechanism, cycle.

Lastly, Zari in 2007 described the framework of biomimicry principles as; organism level, behaviour level and ecosystem level.(Zari, 2007) All three sections divided and examined in 5 subsections. Form, material, construction, process and function. These 5subsection explained as form; the formal expression, material; which material selected, construction; application manner, process; operation method and the function; the capability.(Kandiş, 2019) As well as for the clarifying the method of the classification framework systems the Eastgate Centre building chosen as a case study by Zari. Initially building's behaviour analysed through these 3 mains 5 subsection.

Table 1.Framework for the Application of Biomimicry by Zari.

Level of Biomimicry		*Example - A building that mimics termites:*
Organism level (Mimicry of a specific organism)	*form*	The building looks like a termite.
	material	The building is made from the same material as a termite; a material that mimics termite exoskeleton / skin for example.
	construction	The building is made in the same way as a termite; it goes through various growth cycles for example.
	process	The building works in the same way as an individual termite; it produces hydrogen efficiently through meta-genomics for example.
	function	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil for example.
Behaviour level (Mimicry of how an organism behaves or relates to its larger context)	*form*	The building looks like it was made by a termite; a replica of a termite mound for example.
	material	The building is made from the same materials that a termite builds with; using digested fine soil as the primary material for example.
	construction	The building is made in the same way that a termite would build in; piling earth in certain places at certain times for example.
	process	The building works in the same way as a termite mound would; by careful orientation, shape, materials selection and natural ventilation for example, or it mimics how termites work together.
	function	The building functions in the same way that it would if made by termites; internal conditions are regulated to be optimal and thermally stable for example (fig. 6). It may also function in the same way that a termite mound does in a larger context.
Ecosystem level (Mimicry of an ecosystem)	*form*	The building looks like an ecosystem (a termite would live in).
	material	The building is made from the same kind of materials that (a termite) ecosystem is made of; it uses naturally occurring common compounds, and water as the primary chemical medium for example.
	construction	The building is assembled in the same way as a (termite) ecosystem; principles of succession and increasing complexity over time are used for example.
	process	The building works in the same way as a (termite) ecosystem; it captures and converts energy from the sun, and stores water for example.
	function	The building is able to function in the same way that a (termite) ecosystem would and forms part of a complex system by utilising the relationships between processes; it is able to participate in the hydrological, carbon, nitrogen cycles etc in a similar way to an ecosystem for example.

Table 1: Framework for the Application of Biomimicry Adapted from (Zari, 2007)

To sum up, classification methods have significant role through understanding biomimicry principles correctly also make it easier to the application process and promoting reach through large audience. These different approaches can be chosen as guidance from one end to the other by rather professional designers or the student.

3.Methodology

Case Studies: Large Scale Building Examples Using Animal Inspired Biomimicry as A

Design Stimuli

Because of the impact area of Large-Scale buildings has very important role against to nature. Structural system, waste management systems, water management systems, environmental regulations etc. are very important according to achieve sustainability. Considering this the Large-Scale Buildings that uses biomimicry approach are significant. The function or shape of naturel element can be design stimuli for creating high impact design area.

This section covers adapting way of Biomimicry Design Principles to the Large-Scale Buildings by inspiration of animals. Aimed to highlight differences between different inspiration and application styles.

3.1. Animal Inspired Building Design

Animals has a significant impact of the most of human development. Design stimuli come from animals can be transferred from different sources such as the animal's living arrangements, behavioural style, patterns acts or the shape. Even the structural system of the animal can be source of inspiration. These approach used too many different product design as cars, airplanes, artifacts, houses. Likewise considering to the Da Vinci's works, sketches and ideas based through examination of birds and flying mechanism later gave inspiration to the Wright Brothers. Lodato articulates Leonardo Da Vinci may have been the first true bionics researcher.(Lodato, 2010).

In a similar approach look through architectural examples, earlier versions of the housings in vernacular architecture buildings are created from rural materials and the shape and functions are product of animal inspiration. Such as Hadza building in Africa. The settlements of Aboriginals in Africa get inspiration from Birds Nest. (Sugár, Leczovics, & Horkai, 2017). Moreover, igloos can be shown as an important example through how extreme living habitats of animals become inspiration source for variable problems encountered for humanity. Additionally, source of information comes from animal can be oriented formal imitation or functional imitation.

Hence, the main focus point of this section is Large-scale examples which are uses the animal inspiration as a main design concept and describe their biomimicry approaches.

3.1.1. Orange Analogy and Sea Shell – Sydney Opera House

The Sydney Opera House which is nominated UNESCO World Heritage Site in 2007. Jorn Utzon won the International Architectural competition with the idea of the shape which is inspired from Orange Analogy and structural systems get inspired from Seashell. (Rey-rey, 2022). The opera house contains 5 halls for different usages such as concerts, opera and theatre. Project design and application phase took almost 17 years. It can be shown as an example of computer-based design and working multidisciplinary importance.

Therefore, there were only hand drawing concept sketches for the shape of the opera house. Afterwards by the winning competition looked for a buildable way to the shape. Because the concept form was ready but constructability is depended structural engineers and of course the materials flexibility. With the Ove Arup groups engineering ideas and the flexibility of the reinforced concrete and sure the Jorn Utzon's natural inspiration the Sydney Opera House begun a valid geometry after 5 years work. Arup engineering and architect had countless meetings. Eventually decided to the take each piece induvial such as an orange analogy. In another way geometrically chosen shape was the sphere.(Rey-rey, 2022)

Subsequently the second nature inspiration in this project was the Seashell for the Structure of the Sydney Opera House. If looking beyond of the beautiful shape of the seashell will see the amazingly strong structure. The unique shape provides high resistance, minimum material, large spans, and sheltering characteristic.[2](Rey-rey, 2022)

Thus, Sydney Opera House achieves biomimicry design principles both imitation from shape and function by imitation natural shapes and imitation functional shapes structural abilities.

3.1.2. Cable Structures Inspired by Spider Web- The Munich Stadium

The Munich Stadium complex project build for Summer Olympics in 1972. The architect is Günter Behnisch but the projects maintained as a team work. It selected as a winner project from the competition. Stadium is inspired from the Alps topological shape. Project has contained, multipurpose hall, Olympic swimming hall, and open spaces contains green spaces and water elements.(Wolfgang, 2013) Project application phase took 5 years because of the unusual shape and complex material choice of the stadium.

The project aimed to large-scale but lightweight approach. Besides the structural and material optimization project provides environmental optimization by using retractable roof systems which is adapting itself to the different whether conditions. Also, multidisciplinary was a key attribute. Different materials and systems are connected in it such as sweeping roof, a tensible cable structure, plexiglass.

The idea is come up with competition even so structural application difficulties make jury members uncertain about the project. As mentioned, project aimed to having large spans for activities and but at the same time lightweight. German Pavilion Expo 1967 Montreal project created by well-known architect Frei Otto, is inspiration source for solving structural problems. Although Frei Otto's himself was a part of the design team as Shape Optimizer.(Tomlow, 2016)

Likewise, the most of the elements in nature Spiders are aimed to optimal because of nature's competitive conditions. Complex futuristic Munich Stadium's is inspired by spiderweb design principles. The network created by spider is optimal for material and the span. Production aspect for completing network is overall repetition progress. After the first raw of the web completed, strength is checked and move on to the next raw and the progress continues until the overall network completed.

The roof of the stadium achieves biomimicry both imitation of shape and function.

Roof shape is imitation of natural Alps and the statical problems solved by observing spider webs and adapting the system as a structural element in the roof system.

3.1.3. Pangolin-Waterloo International Terminal

Waterloo International Terminal Station, London completed in 1993 by architects Nicholas Grimshaw& Partners. The train station previously built in 1992, and later The International station added as symbolic and actual threshold between Britain and Continent.(Çingi, 2007) The terminal includes short-term parking area in basement level, second and third levels are for arrivals and lower platforms has contain waiting areas, offices and shops.

The International Terminal aimed gained the same function as airport terminal therefore design methods of the terminal provide passenger minimum bother and maximum speed. Even so, terminal meet 15 million international passenger's need per year.(Grimshaw Architecture, n.d.) The geometry of the terminal decided according to the detailed examination of to the site and accessibility analysis both pedestrian and car. The structure is 400m long and northern tapers are 48.5 m and southern are 32.7m.(Çingi, 2007)

Computational design used as a key element for solving structural and design phase of the project. The limitations of the site and structure was detected with the help of computer aided design. Project's digital twin duplicated 35 times for creating correct adjustments. Accessibility is the key factor of this project therefore departures and arrivals are coordinated through clear, and linear passenger movement in terminal.

The projects mimic The Pangolin's response ability through air pressure force because the terminal's glass panels should resist to occurring air changes according to the trains enter and depart to the terminal.

The unique design of the terminal caused to won several architectural rewards including Mies van der Rohe Pavilion award for European Architecture and RIBA President's Building of the Year Award in 1994. (Çingi, 2007)

Hence, Waterloo International Terminal achieves biomimicry by copying a natural elements function.

3.1.4. Bird's Nest- Beijing Olympic Stadium

Beijing Olympic Stadium built in 2007 by Swiss architects Herzog& Meuron. Its winner of an international competition which the Beijing Municipal Planning Commission announced in 2002. Structural features solved by help of the computational design by Ove Arup& Partners Engineering.

Stadium has 91.000 audience capacity. Although, the stadium also includes facilities as restaurants, offices and shops.(Meuron Basel Jacques Herzog, de Meuron, & Marbach, 2008) The project is approximately 333 meters longs by 284 meters wide and 69 meters tall.(Rogers, Yoon, & Malek, 2008)

However, building's main inspirational source was Bird nest. The façade design elements created by imitating bird nest creation principles. Even so special material called EFTE panels are used because of the similarity through bird nest material. This special space creation system of birds provides Bird Nest stadium acoustic insulation, passive sun shading system, natural ventilation, lighter material solution and even self-cleaning and durable cost friendly material usage.

Therefore, The - Beijing Olympic Stadium achieves biomimicry principles by imitation of animal element but also it provides passive sustainable function at the same time.

e. Whale Skeleton – The Science Museum Principle Felipe

The Science Museum Principal Felipe constructed in 1996-2001 by architect Santiago Calatrava. Project has three floor and 40.000 m² area and 26.000 m² is for exhibition. Although, the building 220 meters long, 80 meters wide and 55 meters high.(Tola & Vokshi, 2013)

Nevertheless, project imitate natural elements and uses these elements as an abstract demonstrated forms such as whale skeletons and bones. These abstractions serve to the structure as modular elements as using repetition, symmetry principles. Tola and Vokshi articulates that Calatrava uses only glass, concrete and steel in this structure. Concrete for the skeleton, glass for the openings and transparency and eventually steel for the structure of building.(Tola & Vokshi, 2013)

Therefore, The Science Museum Principal Felipe achieves biomimicry in imitation of shape and the function at the same time.

3.2. Classification and SWOT Analysis Method

In order to examine Biomimicry Design effects on Large-Scale buildings data collection, classification and SWOT Analysis methods are obtained. First table created by taking consideration to the, examined biomimicry classification methods and Biomimicry levels descripted by Zari, Case Studies are obtained. In addition, limitation for the Case Study is the source of inspiration. The only project uses animal as inspirational source are selected. The second approaches applied classification table is Swot Analysis method applied these selected Case Studies. Bell and Rochford articulate that it is the oldest and best-known framework in management(Bell & Rochford, 2016) Whereas, SWOT Analysis methods relies on the explanation of any system in the spot of key indicators.These key indicators are Strength, Weakness, Opportunities, Threats. Strength and Weakness denotes internal environments whereas Opportunities and Threats denotes external environment.(Mintzberg, 1990)

4.results

Ultimately, as a result of the collecting data, classification and SWOT Analysis methods created two different table. First one is the Classification Table of Case Studies. Represents the Case Studies categorization and organization by depending on the imitation methods, design features and sustainable approaches.

Therefore, second table is created by guidance of Bayhan and Karaca's Swot Analysis table above. By selecting 3 specific sub-headings of the table which are listed as the Strength, Weakness, Opportunities. However, in this article strength represents to the case studies sustainability manners, energy efficiency precautions of to the projects. Weakness covers to the lack of sustainability facilities and overall design and application problems of the building. Opportunities symbolizes the expectations towards design. Finally, Threats includes setbacks in the design and application phases of structure.

Table 2. A Framework for the Application of Swot Analysis Bayhan and Karaca.

SWOT Analysis	
STRENGTHS	**OPPORTUNITIES**
Effective use of energy	Top management support
Higher prestige level	Sustainability focused development policy
Climate adaptation ability	Technological developments
Enhancing comfort	The demand increase to the environmentally responsible buildings
Higher value and rental costs	Incentives from the governmental bodies
WEAKNESSES	**THREATS**
Higher initial or maintenance costs	Unfamiliar systems
Lack of systems expertise	System failures
The need for coordination of different professions	Difficulties in project financing
Special production requirements	Materials do not comply with the standards
Complexity in design	Market conditions

Table 2. A Framework to the Application of Swot Analysis Adapted from (Bayhan & Karaca, 2019)

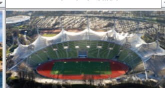
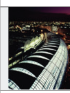
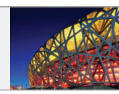
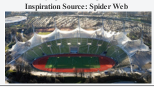
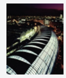
Name of the building	Sydney Opera House	The Munich Stadium	Waterloo International Terminal	Beijing Olympic Stadium
Image of the building			 	
Year	2007	1972	1993	2007
Function	Opera, Concert and Theatre Hall	Stadium, Multipurpose Hall, Olympic Swimming Pool	International Railway Station	National Stadium, Sport Markets
Source of inspiration	Sea Shell	Spider Web	Pangolin	Bird's Nest
Sustainability Manner	Minimizing material usage by providing structural optimization. Adaptation through weather	Minimizing material usage by providing structural optimization. Adaptation through weather condition.	Increasing resisting of glass material through air pressures caused by trains.	Acoustic insulation, passive sun shading system, natural ventilation, self-cleaning, minimizing material usage
Competition Project	√	√		√
Formal Inspiration	√		√	√
Functional Inspiration		√	√	
Design Looking Biomimicry: Solution Based				√
Biology Inspired Design: Problem Based	√	√	√	
Partial Element		√		
Whole Design	√		√	√

Table 3. Classification Table of Case Studies

Table 4. SWOT Analysis Table of Case Studies

Information of the Building		Sydney Opera House - 2007 Opera, Concerte and Theatre Hall Inspiration Source: Sea Shell 	The Munich Stadium-1972 Stadium, Multipurpose Hall, Olympic Swimming Pool Inspiration Source: Spider Web 	Waterloo International Terminal-1993 International Railway Station Inspiration Source: Pangolin  	Beijing Olympic Stadium-2007 National Stadium, Sport Markets Inspiration Source: Bird's Nest 
Strenghts	Effective Use of Engery	√	√	√	√
	Higher Prestige Level	√	√		√
	Climate Adaptation Ability		√		√
Weaknesses	The Need for Coordination of Different Professions	√	√	√	√
	Special Production Requirements	√	√	√	√
	Complexity in Design	√	√	√	√
Opportunities	Sustainability Focused Development Policy	√	√	√	√
	Technological Developments	√	√	√	√
	The Demand Increase to Environmentally Responsible Buildings	√	√	√	√
Threats	Unfamiliar Systems	√	√	√	√
	System Failures	√	√	√	√
	Materials don't Comply with Standards		√		√

As a result of the Classification and SWOT Analysis can be listed as;

- Variable animals can be source of inspiration for Biomimicry design.
- Projects that using biomimicry principles provide sustainability as by;
- Minimizing material usage.
- Material optimization.
- Structural optimization.
- Adaptation towards weather changes.
- Acoustic insulation.
- Passive sun shading system.
- Although, inspirational sources are different can achieve the same sustainability manner.
- Competitions are important towards to increase Strengths of the design by providing higher prestige level.
- Both formal and functional inspiration methods are prevelent in Biomimicry design.
- Biomimicry design principles mostly preferred as solution to ensured problems.
- Most of the designs Biomimicry principles integrated whole design concept.
- All projects demand distinguishing terms of Weakness and Opportunities because of the fact that Biomimicry principles temperamentally demands coordination of different professions to overcome special

production requirements and complexity in design by using technological developments.

- Although, unfamiliar systems and system failures is common Threats for the Case studies.
- Due to the threats Biomimicry designs principles does not always require innovative new materials but also ensure as with the combination of standard.

CONCLUSIONS

Increasing environmental problems become global levels with the Industrial revolution in 18^{th} century. These problems lead governments and also designers to environmentally friendly and nature respect designs. Due to this facts interest increased in direction of Sustainable designs as well as Biomimicry design owing to nature-based fundament. Biomimicry design seeking solution for encountered problems with sustainable approaches under the light of nature's guidance. Therefore, both disciplines have the same attitude towards environmental issues such as energy use, resource consumption. For these reasons, Biomimicry designs are inherently sustainable.

Considering about the role of Biomimicry design according to environmentally friendly design approach, this article has cogitated on Biomimicry Principles as a Design Stimuli.Therefore, scope of the study is Large-Scale Buildings because of the maintenance problems and large impact area. As a limiter to the scope, 4 Case Studies selected by inspirational sources. Eventually, articles main focus point determined as Large-Scale Buildings which are only considers animals as the main inspirational source. The assessment was carried out using methods of information collection, classification methods and SWOT Analysis Methods.

To sum up, it is posited that according to the literature reviews, data collections and Case Studies Biomimicry design is effective way for strengthen ties between nature and architecture. Although, due to the Biomimicry principles and developed technology, architects regained to power to overall control and design freedoms towards Large-Scale designs. On the other hand, it is important to understanding correctly, nature's methods, systems, elements in order to applying correct system to the correct problem therefore, the importance of classification methods was emphasized in order to disseminate to the importance and clarifying the various levels and dimensions of Biomimicry design to a wide audience.

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CHAPTER 7

TOPOLOGY OPTIMIZATION IN ARCHITECTURE PRACTICES

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INTRODUCTION

Design professionals, like architects and engineers, try to balance a project's conflicting goals. Historically, architects' goals have been function and aesthetics, while engineers' have been stability and efficiency. During the medieval period, when great cathedrals were constructed, there were no architectural and engineering specializations comparable to those of today.

There is often a disconnect between the aesthetic or appearance of the structure and the skeleton that corresponds to it, which can be attributed to a disconnect between the vision of the architect and the sensibility of the engineer. In most cases, architects and engineers are concerned about "function," even if in very different senses. We can make the case that the distinction lies in form versus function. The same is concerned with "form," although the architect may have a different interpretation of it. It's not uncommon for architects to use ethereal language when discussing architecture and to focus on how people interact with buildings and design philosophies. It's possible engineers will use terminology that's more specific and quantitative. However, not only do they have different descriptions of it, but also they have different ideas about what it ought to be. Because architects and engineers both play an important part in the design of a building, the end result can either be a compromise, in which case neither the architect nor the engineer is completely satisfied, or a synergistic result, in which case both are pleased with the design, both are satisfied and proud, and the result is a sum even greater than the contributions of both participants. The Roman architect Vitruvius, who lived in the first century AD, is credited with writing that a successful structure should adhere to the three principles of beauty, utility, and strength (*firmitas, utilitas, venustas*). It is not acceptable to have a building that is designed to look nice but does not have sufficient engineering to last. A structure that is only designed to stand, without taking into consideration how it will be used or how people will react to it, is also not acceptable.

In the same way that cathedrals were groundbreaking in terms of both architecture and technology, our designs will also continue to push the limits of what is possible. Design philosophies, design tools, and fabrication and construction techniques have all undergone significant advancements in recent years, which has made it possible to realize designs that simply could not have been constructed even a short while ago. In certain circumstances, an architect is in a position to design something that, in the past, an engineer would have been unable to design. This has opened up new avenues of opportunity. Incredible structures are designed and built thanks to the joint efforts of architects and engineers working in an atmosphere that encourages collaboration. Skyscrapers are a type of building that are an example of one that requires such close collaboration to construct. For this reason, it is believed that evolutionary structural optimization methods will be utilized in the future in this field of design.

PERFORMANCE BASED DIGITAL DESIGN

Early in the development of computer systems, designers and design theorists began to recognize artificial intelligence via performance-based design method's potential. "Geative Design" is the most important term for the use of artificial intelligence in design. In the 1960s, Christopher Alexander developed the word "Generative Design" (Alexander, 1964). Alexander stated in his book "Notes on Synthesis" that it is possible to find the most efficient optimal form in product design using computer technology.

'Design' has dual connotations. It refers to both the object's design action (design as an activity) and the designed object (design as a work), which is the result of the action. This separation is fundamental to generative design systems. Instead of describing the derivative system design object, the construction procedure is encoded in performance based design (Dino, 2012). In other words, during the design phase, the designer can predict what the final product will look like, but cannot fully visualize it. Nevertheless, various alternatives can be evolved from the design created with the derivative system and the modification of the input data.

In derivative design, unlike parametric design, the data entered into the algorithm is either objective data from simulations or the environment, as opposed to the designers' subjective decisions. The most notable illustration of this methodology is "performance-based design." In performance-based design, for instance, the algorithm's encoded variables can be static inputs. In other words, the parameters of the form that comprise the design can be specified in a manner that maximizes static performance.

In terms of shaping the design with the available data, it is also necessary to examine the definition of "Inverse Design." In contrast, the design is determined by qualitative and quantitative values extracted from the system to be designed during the design process (Hirano & Yamada, 1988).

Currently, the 'Reverse Design' and 'Performance-Based Design' approaches share many similarities. In both design processes, the final form of the design is determined not by the designer, but by the method the designer organizes. In the conventional design procedure, the design is entered into the simulation program based on the predetermined criteria, and the simulation result is analyzed by the graphical program. When required, the design is modified and re-simulated, and the final results are compared. This procedure continues in an effort to approach the desired outcome. The analysis engine and the graphical program are intertwined during the design process. The designer does not interfere with the design in order to realize her/his vision, she/he observes the design developed by the computer with the analysis data (Figure 1).

In the early stages of evolutionary design, the relationship between form and performance-based criteria emerged as an innovative viewpoint. Peter Bentley listed the following advantages of evolutionary design: Evolutionary design systems are sophisticated software tools intended for human use; they are not intended to replace humans. It is the most recent in a long line of software innovations designed to reduce productivity, quality, speed, and design costs. Based on these software tools, evolutionary design assumes a portion of the design process. It enables them to automatically improve the performance of their designs based on evaluations by analysis software (Bentley, 1999).

Bentley Systems is a pioneer in engineering software for evolutionary design methods, while Galapagos is in architecture. Galapagos, a plugin for the Grasshopper software, is the most utilized method in evolutionary design. There are two types of "analyzers" in the Galapagos: genetic and evolutionary (Rutten, 2013). The variables that are required to be differentiated in this plugin are connected to the Galapagos plugin. Nonetheless, the maximum or minimum of the resulting data is also associated with this plugin. Galapagos generates a gene pool by entering various numbers into the algorithm's variables. Then, the analyzers determine the values closest to the searched criteria. Thus, the design determines the shape that maximizes the performance of the desired feature.

Aim Of Topology Optimization

Topology optimization (TO) is a method of form optimization that employs computational models to optimize material arrangement inside a user-defined space for a specified set of loads, circumstances, and limitations. TO maximizes the performance and efficiency of the design by removing unnecessary material from regions that do not need to carry substantial loads in order to reduce weight or address design difficulties such as lowering resonance or thermal stress.

Conventional TO employs finite element analysis to evaluate the performance of the design and produce structures that meet objectives such as the following:

-Reduced weight-to-rigidity ratio

-improved strain energy to mass ratio

-decreased ratios of material volume to safety factor and natural frequency to weight.

Although TO has a wide range of applications across industries, in engineering, it is employed during the design phase of new product development to optimize the form in order to increase the stiffness-to-weight ratio. Topology-optimized designs frequently feature freeforms and intricate shapes that are difficult or impossible to construct using conventional production methods. However, TO designs are ideally suited for additive manufacturing technologies, which have more forgiving design requirements and can rapidly reproduce complicated shapes at no additional cost other than the initial investment.

Comparison Of Topology Optimization and Generative Design

In the Computer Aided Design (CAD) arena, generative design and TO have become buzzwords, although it is a frequent misperception that they are synonymous. TO is not a novel concept. It has existed manually for at least 80 years and digitally 20 years, and has been widely implemented in CAD software applications. In TO, a human engineer is required to design the initial CAD model, applying loads and constraints with project characteristics in mind. The software then eliminates extraneous material and generates a single optimized mesh-model concept that is ready for assessment by an engineer. In other words, TO cannot function without an initial human-designed model, limiting the process, its consequences, and its scale. In a sense, TO is the basis for generative design. Taking the process one step further, generative design eliminates the requirement for the first human-designed model by assuming the designer's function based on a preset set of restrictions.

The Process Behind Topology Optimization

Typically, TO occurs at the conclusion of the design phase, when the desired component must be lighter or utilize fewer materials. The designer then determines certain predetermined factors, including applied loads, material type, limitations, and layout. First, structural TO establishes the lowest permitted design space required for product form optimization. The TO software then virtually applies pressure from various angles to the design, evaluates its structural integrity, and identifies unneeded material.

Finite Element Method (FEM), is the most prevalent and practical methodology for TO. FEM considers the geometric design for the minimum space permitted, as well as other aspects, and disassembles the design. Each discrete element is then examined for rigidity, compliance, and unnecessary material. Finally, FEM reassembles the components to complete the design.

In order to validate the design, a threshold for the element density field between 0 and 1 must be determined. A number of 0 voids material in a specified region of the structure, while a value of 1 solidifies the specified region. The designer can then eliminate all unneeded components from the model and complete the TO portion of the design. Prior to the advent of additive manufacturing, designers discarded many of the intricate designs developed by TO because they were impractical to manufacture and their promise remained untapped.

In the age of computers, architects and structural engineers frequently employ 'evolutionary' design strategies and genetic algorithms to optimize structures and define forms (Coenders & Bosia, 2006). Using finite element analysis as a framework, Evolutionary Structural Optimization (ESO) was created specifically for engineering applications. ESO is founded on the simple premise that the optimal structure (maximum stiffness, minimum weight) can be achieved by progressively removing inefficiently used materials from the design domain . The original ESO method did not permit the restoration of deleted elements. As such, it differs from other optimization algorithms, which were frequently based on a general mathematical approach and now have a broad range of applications. ESO, on the other hand, is strictly limited to shape optimization and is governed by very simple principles. Because of this, the term "evolutionary" is an inappropriate and possibly incorrect adjective to describe this algorithm. After Mike Xie and George P. Steven, both of RMIT, developed this method in the early 1990s of the 20th century, it became widely known afterwards (Januszkiewicz & Banachowicz, 2017).

Discretizing a volume or region, defining the forces that are operating on it, and then running a FEM analysis are the three steps that make up the core of ESO. The deletion stage of the ESO method is carried out by making use of the analysis data. The purpose of this stage is to remove the "least beneficial" material from the composition of the structure. ESO creates a topology or shape by deleting material that isn't being utilized efficiently, and it does this based on the results of a finite element analysis. It keeps doing that until it finds a balance between the volume and the stiffness of the shape (Figure 2). The findings suggest that organic and even skeletal structures can achieve the best results, which is probably why this algorithm was given the same properties as natural development. It should come as no surprise that the organic shapes have a considerably greater measure of complexity than the more traditional orthogonal designs.

Topology Optimization and Biomimicry

Biomimicry is an example of an effective application of evolutionary design tools in the present day. Although the term biomimicry first appeared in the scientific literature in 1962, by the 1980s it was commonly used by materials scientists. Some scientists prefer "biomimetic" or, less frequently, "bionic." The number of studies in this field has increased over the past decade. Prof. Dr. Julian Vincent, an expert in the field, defined bio-imitation as "the abstraction of good design in nature," whereas author Janine Benyus defined it as "the conscious imitation of nature's genius" (Pawlyn 2011). Numerous recent studies have shown that the outcomes of TO are directly related to biomimicry. Fundamentally, biomimicry or bionic design is based on shapes or patterns of behavior that living things in nature adapt to suit a particular need. These capabilities may include material economy, ideal form, the least amount of material use, and most effective time (Pedersen Zari, 2007). Modern computer technology makes it possible to examine and replicate the forms created by nature (Senegacnik and Kuzman 2014). When the chassis of a drone is developed utilizing TO, for instance, the final design strikingly resembles the pelvis of a flying squirrel (Figure 3).

MAIN APPLICATION FIELDS OF TOPOLOGY OPTIMIZATION

Topology optimization approaches allow for the creation of high-performance, energy-efficient, and lightweight designs that are applicable in a variety of industries. In general, it has a great deal of potential, especially in situations where the weight-to-strength ratio of a design is crucial..

Aerospace

Due to the significance of weight reduction, aeronautical engineering and aeronautics are a perfect fit for TO. TO has been utilized to improve the layout design of airframe structures, such as stiffener ribs and airplane brackets. In addition to facilitating structural lightening, TO can assist in unlocking the possibilities of modern production technologies such as additive manufacturing and composite materials, which are gaining popularity in the industry (Zhu, Zhang, & Xia, 2016).

Automotive

In the automotive industry, TO strikes a balance between the need for lightweight components for fuel efficiency and power and the need for a body that can endure torque and impact. The motorsports industry requires lightweight vehicle designs that do not sacrifice performance

(Tyflopoulos, Lien, & Steinert, 2021). In this direction, a high stiffness-to-weight ratio must be achieved in nearly every automobile component. Therefore, the design for manufacturing is essential for Formula Student teams (Bikas et al., 2015). In the racing industry, topology-optimized chasis and components have recently been implemented. In addition to reducing mass, TO can enhance passenger safety by dictating the manner in which a structure falls during an accident.

Medical

Additive manufacturing is appropriate for the production of medical implants because it enables medical practitioners to construct free-form shapes and porous structures . The designs can feature lattice structures that are lighter, enable superior osseointegration, and last longer than other implants due to topological optimization. Optimizing the designs of biodegradable scaffolds for tissue engineering, porous implants, and lightweight orthopedics is also a capability of TO tools (Zhang et al., 2022). Also utilizing topological optimization are nanotechnology applications such as cell manipulation, surgery, microfluids, and optical systems. In the medical industry, TO is utilized not just in implant design, but also in a variety of other fields, such as the development of medical hand tools (Sun, Liu, Xu, & Lueth, 2019).

SOFTWARES

The versatility, velocity, and sturdiness of TO are becoming more obvious to engineering product designers. The software industry responds by incorporating the essential toolkits into current products or by building new software solutions. The majority of engineering disciplines use TO with the following software: Altair Inspire & Altaire OptiStruct, Ansys Mechanical, Autodesk Fusion, Solidworks, Creo, nTopology, Tosca Structure, Comsol, and Nastran.

One of the pioneering software packages that presents the derivative design method as a ready-made package is the Catia software that Frank Ghery used while designing his avant-garde structures. The deployment of the generative design module within the Catia software took place in 2018. Another design software that has developed the generative design module in recent years is Autodesk Fusion 360. In this software, which is frequently used by mechanical engineers and industrial product designers, the generative design module was added in 2018.

Due to the interoperability of other CAD programs, the Grasshopper plugin in the Rhinoceros software is widely used in parametric architectural design field. The preliminary studies of this current method can be provided with different add-ons within the Grasshopper software.

The oldest of these plugins is Millipede, which was developed in 2017. In Millipede, the structural analysis is done by the computer on which the plug-in is installed . The tOpos plugin, which saves a lot of time by performing the structural calculation process 100 times faster via the computer's graphics card (GPU) instead of the computer's processor (CPU), is another plugin that works within the Grasshopper software (Bialkowski, 2017). However, since this method can be performed with graphics cards with CUDA support, it can be used on computers with powerful hardware. Another generative design plugin is Ameba (Xie, Zhou, Shen, Wang, & Zhou, 2018). The most important feature of the Ameba plugin is that the calculation is done on its own servers. By connecting designers who want to create forms to central servers, where the software is developed, the calculation process is much faster. In addition, the results of all samples produced using this plugin around the world are accumulated, and the algorithm is updated and continues to be developed (Yildirim, 2019).

ARCHITECTURE PRACTICES

In the past two decades, advancements in construction industry design software and the maturation of related production procedures have led to the construction of structures with intricate and striking appearances. Others are criticized for the lack of harmony between their architectural design and structural issues, despite the fact that several have earned accolades and are considered regional landmarks. The goal, therefore, is to produce designs that simultaneously incorporate architectural operational functions, aesthetically pleasing effects, and sensible structural performance. Inspired by structural morphology (Motro, 2009), which involves form, forces, material, and structures and aims to develop a structural system with a harmonious synthesis of these four aspects, architectural morphology is defined by extending the connotation of structural morphology to encompass structural performance, architectural functions, and aesthetical requirements.

Existing architectural implementations of TO are the result of significant research and time-consuming efforts, frequently with the assistance of civil engineering specialists. The tools utilized for this project are either highly specialized and costly engineering software or custom-built toolkits for the current issue. However, general purpose engineering tools available on the market that feature structural optimization algorithms have several additional limitations that reduce the likelihood that architects will use these methods to enhance their design process. The software's detailed user interface and the abundance of options and decisions that the user must make it a highly specialized application designed for a limited user base.

Early Proposals

At the start of the twenty-first century, architectural design proposals derived from TO began to emerge. Arata Isozaki and Mutsuro Sasaki were the primary designers of the period's earliest works. The Illa de Blanes project, a multi-space cultural and tourism structure in the coastal town of Blanes, was among the first to employ ESO digital techniques in architectural design. Isozaki & Associates carried out the project from 1998 to 2002 with the aid of Japanese structural engineer Mutsuro Sasaki. Using an optimization program and virtual concrete blocks, Isozaki created load-transfer columns in the shape of a tree. These one-of-a-kind shapes were intended to serve as an emblem for this beach resort. However, budgetary restrictions have caused the project to be suspended (Januszkiewicz & Banachowicz, 2017). It was suggested to build a big structure on the shore with a combination of commercial, public, and recreational activities, offering 75,000 m2 of attractive useable space. In addition to organically formed columns, this design features a 3D Extended ESO roof (Huang, Radman, & Xie, 2011).

2003 marked the completion of Arata Isozaki and Matsuro Sasaki's enlargement of the Santa Maria Novella train station in Florence. It is the busiest station in Italy, servicing 59 million passengers each year. It was the first effort at entering a global architectural competition with ESO computerized design tools (Figure 4). The dimensions of the new train station are 400 meters in length, 42 meters in width, and 20 meters in height. This complex's roof provides a vast lower space for facilities, while the roof itself serves as a landing strip for small planes. Arata Isozaki's design entry has a flat roof supported at multiple points by naturally curved columns created using 3D Extended ESO. It was envisioned that supports resembling tree branches would be constructed of reinforced concrete with a box profile. The idea was not realized since the second-place entry was defeated with a design by Norman Foster.

Akutagawa River Side Office Building in Takatsuki, Japan, 2004

The Akutagawa River Side project in Takatsuki City represents the first application of computational morphogen-process. In late April of 2004, this four-story office building was completed. It is intended to revitalize the shopping arcade, which runs from the north front adjacent to the Takatsuki Japanese Railway station, as well as the entire urban area. Extended ESO method (EESO) was utilized to determine the shape of the building's walls. Two of its side walls, those facing west and south, were optimized with EESO and constructed with reinforced concrete. It succeeds in highlighting the facade's design and structure as a unified layout. Typical dead and live loads, in addition to dynamic seismic loads, were considered. Afterwards, the findings of the evolutionary design were validated by an elastoplastic numerical analysis based on deflections and cracking patterns. The structure's design space and optimization space are two-dimensional in this structure (Figure 5).

Crematorium in Kakamigahara, Gifu, Japan, 2006

Toyo Ito's Crematorium in Kakamigahara Gifu, the 18-centimeter-thick curvilinear reinforced concrete roof shell free form was examined using Sensitivity Analysis, a systematic method for assessing curved surfaces to obtain an effective structural structure. According to Ito's design, a white concrete roof rises up to 11.5 meters above a travertine platform adjacent to a small lake. The interior of the structure is delineated by 19 mm thick glass walls and columns that are randomly dispersed from the undulating roof. In partnership with structural engineer Mutsuro Sasaki, who used digital programming 3D EESO to define the most efficient form for the undulating surface, a compromise was struck between functional, service, structural, and aesthetic criteria, resulting in the roof's design. Toyo Ito and Associates collaborated with Sasaki Structural Consultants to digitally optimize the building's landscape and structural design (Figure 6).

Rolex Learning Centre in Lausanne, Switzerland, 2008

The engineering and construction of the Rolex Learning Center at the Ecole Polytechnique Fédérale de Lausanne is very experimental and inventive. EESO is a new shape-analysis method developed by Mutsuro Sasaki in collaboration with SANAA, Bollinger+Groove, and Arup. The building consists mostly of two complicated geometric "shells" (Figure 7). The primary characteristic of this 160 m to 120 m structure is that its floor conforms to the convex shape of the project's two shells. Within the two shells are eleven unrestrained arches. The smaller shell rests on four 30 to 40 metre-long arches, while the bigger shell rests on seven 55 to 90 metre-long arches. As this circumstance is extremely uncommon. Thus, even a shell can incorporate a wide variety of design criteria that go well beyond structural considerations. Tracing performative capacities inside a particular morphology has supplanted traditional form-finding techniques. As load-bearing qualities vary like articulation across the landscape, no place constitutes a pure structural type. The research also identifies trouble spots that would demand an excessively thick concrete casing. Redirecting the force flow between the shell perimeters by modifying the design, size, and position of the patios remedied the wavy tensile force progression, excessive bending movements, and redirected forces, as well as the lack of support points in the patio sections. This iterative approach to measuring performance in conjunction with architects requires continuous design and evaluation cycles (Januszkiewicz & Banachowicz, 2017).

Qatar National Convention Centre, Doha, Qatar, 2008

It was not until 2008, when the Qatar National Convention Centre project in Doha was approved for implementation, that there was a real opportunity to build this revolutionary structure. Together with Buro Happold, an executive design was created in which the concrete structure was replaced with one made of steel. This design features a massive framework resembling two interwoven trees to support the outside canopy of the building (Figure 8). The forms are symbolic references to the Sidra tree, which is a cultural landmark in Qatar (Naboni & Paoletti, 2018). The finished product is 250 m in length, 30 m in width, and 20 m in height; it features a prominent tree-like structure made of twin tubes supported by steel bars, which closely resembles conventional outlines derived through shape and TO. In his work, Sasaki investigated geometric optimization strategies, i.e. techniques for optimizing the geometry of a building, beginning with its initial design, without compromising its topology (Dapogny et al., 2017). The structure resembling dendrites is the most difficult aspect of the structure's creation. Each component of the dendric forms must comply with optimal load transmission methods and suit the building's functional needs (Pak, Orhon, & Akgun, 2015).

RECENT RESEARCH APPLICATIONS

The design process for structures (buildings, bridges, hangars, etc.), from the stage of form conception to the selection of the structural system and subsequent design steps, is a multi-disciplinary process involving many disciplines, such as structural engineering, ecological/bioclimatic design, acoustic performance, etc. Parametric design is a technique based on algorithmic thinking in which geometry is formed via the expression of parameters and their relationships; it enables the discovery of a variety of possible solutions by varying the parameters. In recent years, the application fields of topology opti- mization have evolved (both in small and big scale types of structures); more recently, topology opti- mization has been utilized to aid architectural conceptual design in the development of complicated structural systems. The establishment of manufacturability constraints is one of the most important phases of TOPs formulation, particularly within the context of architectural conceptual design. In the creation of complex structural systems, topology optimization can be effectively combined with additive manufacturing for smaller-scale structures (Sotiropoulos, Kazakis, & Lagaros, 2020).

3D Printed Node Design by Arup

Due to the manufacturability of large-scale applications of TO-generated shapes, a number of recent studies on component-level design have been conducted. Together with Autodesk, Arup developed a 3D-printed joint created by a TO algorithm. TO methods are used to replicate an existing structural node that is part of a tensegrity structure. The three illustrated structural nodes are all designed to support the same structural loads, which in this experiment are tensile forces. The first part is the original connection that accepts jaw fittings, while the regenerated shape is designed to accommodate swage studs using Arup's most cutting-edge optimization and design techniques (Figure 9). This rebuilt joint is equipped with an optimization algorithm and an integrated FEM solver, which is an expanded SIMP method analysis tool. A comprehensive battery of material testing was administered in order to specify items utilizing additive manufacturing technologies in the construction industry (Galjaard, Hofman, & Ren, 2015).

3D-Printed Stay-in-Place Fromwork by ETH Zurich

ETH Zurich is an important research organization developing TO building components. Their digital building technology laboratory focuses on design creation using cutting-edge digital fabrication equipment. In their article titled 3D-Printed Stay-in-Place formwork for Topologically Optimized Concrete Slabs, Jipa et al. describe a method for implementing TO to produce concrete forms (Jipa, Bernhard, Meibodi, & Dillenburger, 2016). The authors offer an experiment that demonstrates a practical implementation of topology-optimized roof slab construction (Figure 10). TO can be utilized as a design strategy to minimize material without compromising an object's functioning; however, the constructability of such computer models makes it difficult to implement in practice.

Smart Slab by ETH Zurich

Smart Slab was deployed by the same lab as an ongoing research project. Smart Slab is a lightweight concrete slab with many scales of three-dimensional geometric differentiation. The Smart Slab employs 3D-printed formwork for casting and spraying concrete in geometrically complicated patterns, with the added advantage that geometric complexity and distinctiveness incur no additional production costs (Figure 11). Using the structural grid as a starting point, the computational design method generates a basic mesh shape with several dozen faces. In contrast to the previous experiment's single-element analysis, these slabs are integrated with the remaining building components to visualize the overall building structures (Leschok et al., 2018).

Concrete Choreography by ETH Zurich

Concrete Choreography is an experiment of 3D-printed column created by ETH Zurich. In the heart of the Alps, 3D-printed concrete columns serve as the stage set for a dance event. In contrast to the smart slab, these columns are printed hollow with fillers, therefore formwork was not required (Anton et al., 2020). The cutting-edge 3D Concrete Printing (3DCP) process stands at the core of the project Concrete Choreography (Figure 12). The project liberated design thinking from conventional concreting techniques and fostered an holistic approach to the conception and realisation of a novel, multi-layered material system.

3D Printed Bridge by MX3D

MX3D, a Dutch startup, has produced the world's largest 3D-printed structure, expanding on the topic of 3D printing and constructing TO-generated objects. The MX3D Bridge is an experimental project produced in the Netherlands by structural engineers and designers using the most recent robotic 3D printing technology (Gardner, Kyvelou, Herbert, & Buchanan, 2020). Fully 3D-printed in stainless steel, the bridge fuses conventional steelwork and innovative digital modeling to create a structurally solid piece of urban public infrastructure (Figure 13). The MX3D bridge is the first instance of the TO technique being used to build civil infrastructure. MX3D provided software that generates the analysis and iterates optimal shape alternatives for the design, using Arup as the primary structural engineer (Woo, 2020).

CONCLUSION

When it comes to the development of forms, TO software offers limitless options. Each new boundary condition, the shape of the design space, or the constraints, will result in the generation of a new form that is tailored to the user's specifications. Using parametric design to implement the form-forming principles of topological optimization enables designers and architects to search for architectural form of structures and ideas in a streamlined and straightforward manner. The use of numerical methods as a basis for generating forms has led to the creation of intriguing, intricate structures with increased value. It is not constructed of prefabricated architectural solutions, but rather a unique response to a specific situation.

Geometric shapes in architecture are never the optimal shapes obtained from a form-finding process driven solely by structural optimization; rather, they embody and integrate multiple criteria. It could be assumed that there is a correlation between these natural processes and the design techniques given in this book. This can also be seen as an evolutionary technique that is not constrained by the availability of calculation and analytic techniques. Each particular structure must be completely specified and modeled in order to be evaluated in digital processes. Cognitive form, through its tectonics and space, alters the established design tenets. The complete integration of structural engineering into the architectural design process does not guarantee good architecture or innovative space and forms, but it makes their existence possible. Now, more than ever before, engineers are embracing the natural world and poetically utilizing its logic to achieve architecture's potential.

Future studies will primarily concentrate on enhancing optimization techniques for skeletal structures, such as space trusses and frames. This is because it is possible to directly express computational findings as constructible configurations in the real world. There are numerous methodological obstacles, such as buckle considerations and production limits. This leaves a lot of room for ongoing research and development aimed at providing architects and engineers with consistent, efficient, and dependable computational design tools.

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FIGURES

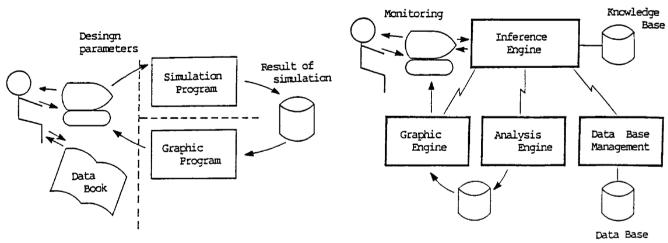

Figure 1 Conventional design process (left), Multi paradigm expert system architecture (right) (Hirano & Yamada, 1988).

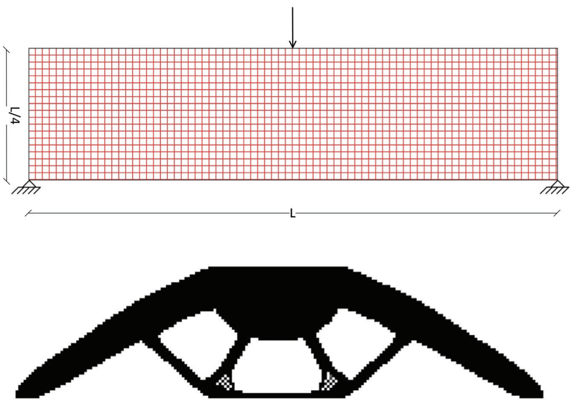

Figure 2 Topology optimization logic; the conditions of boundary, load and support (above), classical TO method result (below) (Sotiropoulos et al., 2020)

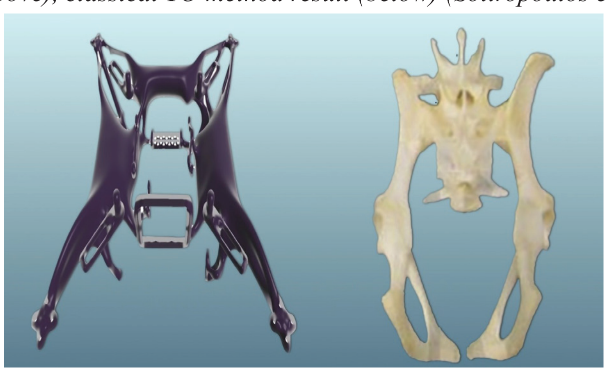

Figure 3 Topology-optimized drone chasis (left), flying squirrel pelvis (right) (Conti, 2017)

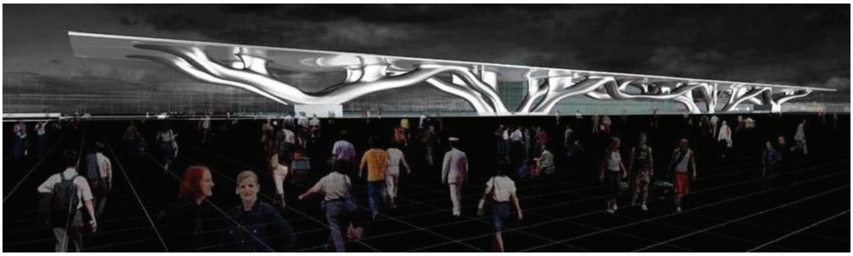

Figure 4 Mutsuro Sasaki Structural Design Office and Arata Isozaki Atelier, proposed 3D model for the train station Santa Maria Novella in Florence, 2003 (de Marco, 2018)

Figure 5 Akutagawa River Side Office Building in Takatsuki, Japan, 2004 (Omori & Ohmori, 2008)

Figure 6 Crematorium in Kakamigahara, Gifu, Japan, 2006 ("Meiso No Mori Municipal Funeral Hall," 2013)

Figure 7 Rolex Learning Centre in Lausanne, Switzerland, 2008 ("Rolex Learning Center," 2010)

Figure 8 Qatar National Convention Centre, Doha, Qatar, 2008 ("Arata Isozaki & Associates," 2011)

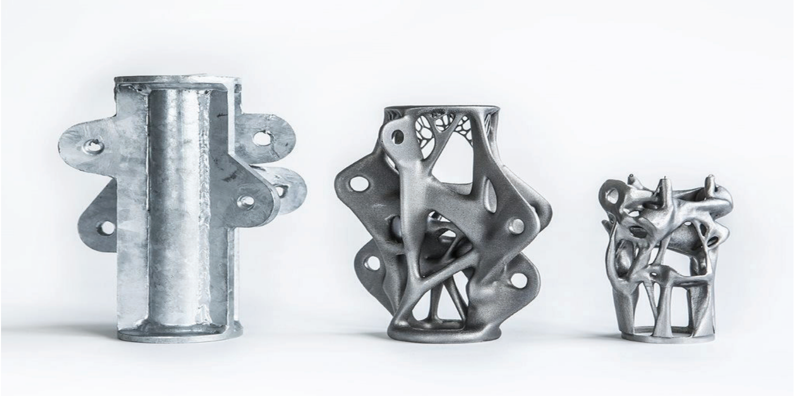

Figure 9 3D Printed Node Design by Arup (Galjaard et al., 2015)

Figure 10 3D-Printed Stay-in-Place Fromwork by ETH Zurich (Jipa et al., 2016)

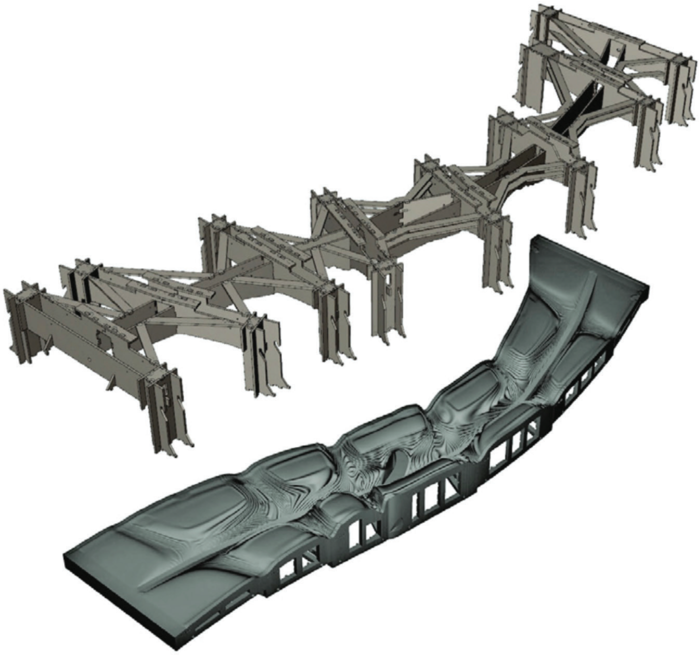

Figure 11 Smart Slab by ETH Zurich (Leschok et al., 2018)

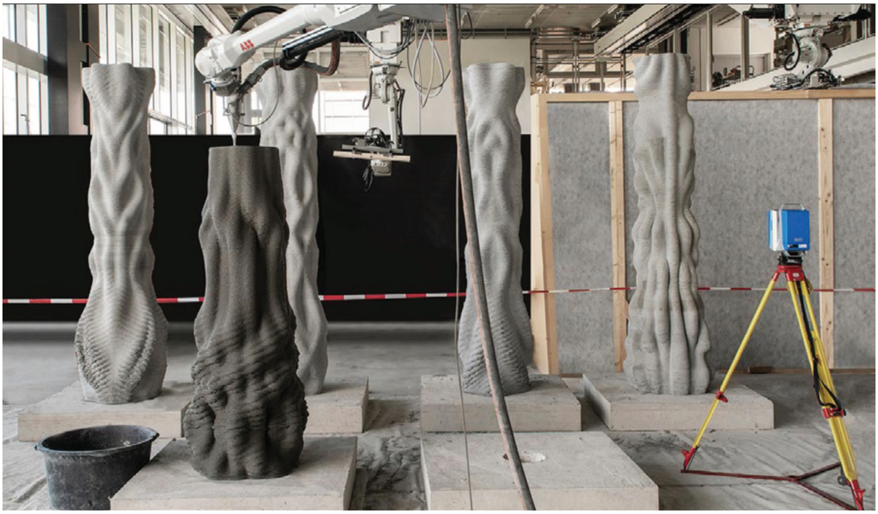

Figure 12 Concrete Choreography by ETH Zurich (Anton et al., 2020)

Figure 13 3D Printed Bridge by MX3D (Gardner et al., 2020)