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Effects of Building Materials on Sustainable Facade Design

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Abstract
Facade designs are crucial in creating the identity of buildings, as they allow buildings to interact with users, form ideas, and evoke curiosity. Designers have been working to develop materials for facades since 7000 BC, with sustainability being a key subheading in the innovation process. Sustainable architecture has evolved, influenced by lifestyles, geographical conditions, social and physical needs, and economic reasons. Through the examination of many instances of the material's historical evolution, the purpose of this research is to investigate the impacts of the material that is utilized in sustainable building designs. It also examines examples of the use of nanotechnological facade materials, which are among the sustainable facade technologies of the future. Within this context, the methods being followed about the issue have been determined and the possible solutions have been discussed.
Keywords: Sustainability, Building Materials, Facade Design, Bio-Materials, Sustainable Architecture

1. Introduction

Architecture, which most accurately reflects cultural and technological developments at all stages of civilization, is very exciting as it is the most concrete image of human history. (Roth,2000)
The concept of sustainability used in architectural design that aims to minimize the environmental impact of buildings in the use of materials, energy, development space and the ecosystem, began to become one of the important methods used in industrial and architectural designs. Sustainable architecture uses a conscious approach to energy and ecological conservation in the design of the built environment (Afara et al., 2024; Amen et al., 2024). In the study, facade systems from past to present are examined, the effects of the materials used on the facade are determined, and the systems that are foreseen to be used in the future are evaluated.
This research examines the advantages that can be achieved by the development of facades, which are large parts of the of the building production cost and the climate crisis, and also reveals the facade-material relationship.
Facades are the first parts of a building that users experience. For this reason, facade designs, with their perceptual structure, are very important items those enable buildings to come into contact with people, to form ideas about the building. The main objective of this study is to examine the facade materials and determine the effect of sustainable materials on facade design which can be used as a resource in the production of eco-friendly facades.
The main questions of this study are;
• “Do the materials used have a decisive effect on the facade design?”
• “How much is it possible to reduce the carbon footprint of the building through façade materials?”
As a result of this research, it is aimed to examine the effect of sustainable materials on facade design by examining facade materials. Thanks to these target facade systems, eco-friendly buildings can be designed by reducing the carbon footprint of the building.

2. Material and Methods

The development of the facades, which are reflections of the buildings, and the materials that make up these facades were examined. Starting with the concept of facade, examining the historical development of facade material, facade designs before the Industrial Revolution, and facade designs after the Industrial Revolution. Technological developments that emerged with the development of materials and the impact of these innovations on facade design were determined. Then, technological developments in sustainable facades were discussed. Technologies in sustainable facades, developments in sustainable facades with today's technologies, and future technologies have been recorded thanks to literature reviews. The data found here was tabulated and analyzed.
Method of research:
1- Determination of today's international standards of sustainability technology through literature reviews.
2- Examination of the historical development of the facade material. It was determined as.

3. Results

Human beings have been trying to create space since ancient times. Architecture is the art of creating a space; It reveals the cultural, economic, social, technological, and intellectual reality of the society. (Güvenli, 2006)
In this section, the development of the facades, which are reflections of the buildings, and the materials that make up these facades are examined. Starting with the concept of facade, examining the historical development of facade material, facade designs before the Industrial Revolution, and facade designs after the Industrial Revolution. Technological developments that emerged with the development of materials and the impact of these innovations on facade design were determined.

3.1. Concept of Facade:

The word facade is a loanword from the French façade, which in turn comes from the Italian facciata, from faccia meaning 'face', ultimately from post-classical Latin facia. The earliest usage recorded by the Oxford English Dictionary is 1656. (C. & Simpson, 1989) In the Dictionary of architecture, it is defined as 'each of the visible surfaces of a building, especially the front face or the view viewed from infinity in a direction perpendicular to the building face' (Hasol, 1990).

As an external reflection of an identity, the facade is more than a material border. The surrounding area reflects the image of space at the very first moment. The facade is a sign of internal organization, it indicates social meaning and accessibility. The facade is the preservation of a meaning of the visible and the invisible, the secret and the hidden, but also the indication of it. (Vandevivere, 1983)

Facades are the first connection points between buildings and people. Therefore, it has a great role in determining the relationship between people and buildings. Considering that they are considered external reflections of buildings, facades reveal the cultural, social, economic, and technological reality of the society.

3.2. Historical Development of Facade Material:

We cannot interpret facades only as the outer shell of the building. It is a very important item in determining the privacy between the main users of the building and the people outside and the physiological needs of the users.

As a result of all these reasons, human beings have studied the facades and the materials used on these facades when creating spaces since ancient times. It has been known that starting from 7000 BC, people took the first step towards sustainable materials when they started to use adobe bricks by combining clay, soil, and straw and drying them under the sunWith the increasing energy problem that started with the Industrial Revolution, the concept of sustainability has developed greatly with the innovations in materials that have also entered architecture. As the development of materials from adobe to smart facades progresses, facade design has also changed and developed many times thanks to the opportunities brought by these materials. By examining the facade designs and materials of each period throughout history, we can obtain a lot of information about the living conditions of that society.

3.3. Facade Design Before the Industrial Revolution:

In prehistoric times, facades in people's buildings were not a part of the design process, but the end product. However, when we evaluate the materials that make up the facades of the buildings, we can easily see that people are trying to improve the materials that nature offers them.

If we examine Çatalhöyük, a Neolithic Age settlement, the main materials used are; We see that it is adobe, reed, and wood. They built the columns of the buildings from wood and the ceilings from compressed clay and reed. People entering adjacent buildings from the roof did not leave any openings on the facades to protect themselves from the attacks of the enemies and wild animals.

In Egyptian architecture, solid, giant-sized, and magnificent structures were built, focusing on the other world, consisting of geometric forms built with mathematical meticulousness, as if they wanted to make people believe in immortality. Egyptian architecture underwent only minor changes over 2,700 years, during thirty-one dynasties. The aim of Egyptian culture and the architecture that includes its institutions is continuity and order; This constant effort against time, death, and degradation has turned architecture into an activity devoted to the service of tradition. (Roth, 2000)

It can be said that Egyptian Architecture consists of simple and smooth geometric forms and linear designs. They created the first examples of prefabrication using stones brought from distant countries.

Even though Greek architecture differed in each state and age, the structures did not deviate much from the scheme created in the archaic age, except for minor changes. Unlike the Egyptians, the Greek civilization built structures close to human scale. Greeks, seeking balance and symmetry, generally used stone in their buildings. Greek architecture is the embodiment in stone of the effort to find the ideal balance between extremes, that is, the middle. In the understanding of architecture, this turns into the balance between vertical load-bearing elements (columns) and horizontal load-bearing elements (eaves beams), and between movement and immobility. (Roth, 2000)

In Greek buildings consisting of straight lines, order and symmetry, repetition and rhythm are the main features. The use of two different orders in the same monument from the end of the 5th century and the invention of the Corinthian capital indicate the effort to enrich the buildings. Since the Anatolian and Egyptian rulers were the ones who built the most buildings after the 4th century, buildings began to be built much larger and more ornate, and the simplicity that was characteristic of Greek architecture was lost. (Mutlu, 2001) Unlike other civilizations, the dimensions of pre-shaped stone building elements in Greek and Roman architecture; It is not applied for technical reasons or cost reduction concerns, but rather with the desire to achieve a certain aesthetic harmony in the proportions between different parts of the buildings.

Gothic architecture, which emerged in France in the 12th century, spread to various countries in Europe and continued until the end of the 16th century. Gothic architecture, which emerged under the influence of clergy who wanted to establish authority over the people, is mostly seen in churches in Europe. Since the general purpose is to glorify God, detailed decorations, ribbed vaults, and pointed arches are frequently seen in pointed cathedrals rising towards the sky.

With the Gothic architecture, which was based on a load transmission system, the walls ceased to be load-bearing, and with the opening of high windows, the use of stained glass began to emerge to create a mystical environment in the

building. Just like the stone, brick, or cement coverings of the buildings built by the Greeks and Romans with the column-lintel system, the stained glass windows located between the arches supported on columns in the medieval cathedrals are examples of curtain walls that have existed anonymously for centuries. (Hunt, 1958)
When a general evaluation is made, architectural styles before the Age of enlightenment lasted for centuries, and there was no need to search for new construction techniques on the existing materials used. When the development of structures is followed, the change that occurs is the product of formal searches, not technological searches.

3.4. Facade Design After the Industrial Revolution:
As a continuation of the Enlightenment movement that started in the 17th century, the industrial revolution, which led to major changes in the social structure in the 19th century, manifested itself in the field of architecture, as in every other field. In the late 18th century, in the Age of Reason, people understood what style meant and began to become aware of different styles. Horace Walpole's summer house on Strawberry Hill was one of the first signs of people consciously choosing the style of their own buildings, as if they were choosing the pattern of wallpaper (Gombrich, 2002).
In the 19th century, new building types were needed due to migration from villages to cities due to production and consumption. Due to the wars, there was a housing deficit and this deficit could not be met with traditional construction methods. Developments in materials and techniques have industrialized construction, resulting in factory production gaining prominence.19. Sufficient progress could not be made on natural materials such as wood, stone and terracotta, which were used until a century ago, and the structures were built as the materials allowed. With modernization and the development of technology, new materials have emerged. Iron, glass and, towards the end of the 19th century, concrete became the building elements of the new age.
The Crystal Palace building is the symbol of this new era. For the first time in history, the building was built with pre-fabricated construction parts. Thanks to this new system introduced by the British, not only building construction times were shortened but also costs were decreasing.
Kristal Palas has shaken the architectural conventions based on the understanding of composition based on the perfect harmony of the piece with other parts and the whole, and has instead brought a brand new understanding that nakedly displays the constant repetition of a modular structural unit and its possibilities of combination and permutation, without trying to clothe it with an expression. (Korkmaz, 2001) However, new building materials were only used in engineering structures such as bridges and factories.
The artist tried to give his low-cost products an expensive appearance with decorations, as the bourgeoisie, the new rich class that emerged in the social sphere as a result of the Industrial Revolution, lived in cities and had capital, demanded objects that increasingly used historical styles and decorations, which they saw as symbols of wealth and status. This caused 19th century design to hide behind the past and past styles. (Kaprol, 2000) Since the 19th century, architects have repeated traditional architectural styles rather than using the innovative opportunities brought by new building materials; Architects who exhibited a revitalist approach with names such as New Gothic, New Renaissance, New Baroque, New Rococo, New Classicism later changed their approaches. By the end of the 19th century, a reaction to this neo-classical approach arose. Art historian Heinrich Wölflin, in his article in 1888, made the determination that 'architecture expresses the attitude of the age towards life'. Twentieth-century architecture had to express its uniqueness, celebrating electric lighting, radio communications, automobiles and airplanes. The century that was born would be the century of machinery, speed and movement, and the architecture of the new age would definitely reveal this mechanization. (Roth, 2000)
Unlike the 19th century, as we entered the 20th century, a modern understanding of architecture emerged by taking advantage of the possibilities of the machine. The main idea of these newly formed modernist movements was that architecture should use the tools of the age according to their unique characteristics and they built their buildings with this principle.
The emergence of the Art Nouveau movement, which was born in Brussels at the end of the 19th century, is associated with the problems of industrialization and growing economies. Even though the Art Nouveau movement did not simplify art, it advocated that architecture should be separated from traditional forms and have an original understanding of designs. Art Nouveau, which was influenced by Japanese art such as the Arts and Crafts movement, aimed to bring dynamism to architecture with curvilinear-vegetal motifs.
All movements that emerged after Arts and Crafts, Art Nouveau, and Art Deco, which developed against the eclectic attitude at the end of the 19th century, until post-modernism, are examined under the title of modern architecture. (GÜVENLİ,2006)
The main one of these movements is the Futurism movement, which emerged in Italy in 1909. Architects in the Futurism movement (using glass, iron, and plastic-based materials) aimed to create a simple architecture that received light and rejected horizontal and vertical lines and cubic forms.
In architecture, many works from the early 20th century to the present have been classified under the name Expressionism. However, this movement includes Futurism, Purism, etc. It was put forward through some manifestos. Expressionism is not a collective movement of artists who agreed with each other but should be considered as a classification that can be made according to the qualitative values of the non-serial, interesting, and original works of some individualist architects, which emerged as a result of their unique behavior. (Kortan, 1986)

In the 1970s, architects began to react to the Rational Architecture movement, which had dominated the understanding of building since the beginning of the 20th century, thus Post Modernism emerged. Since these years, structures that formally express the inspiration from machines have emerged. In the 80s, the 'High Tech' movement emerged with the reflection of technological developments on the structure. Adopting an expressionist approach, high-tech structures reflect vertical circulation elements and plumbing channels to the outside, creating structures like large machines. Norman Foster, Richard Rogers, and Renzo Piano are the pioneers of this movement.
Architects, the De Constructivism movement born in 1988, rejected all these understandings and began to search for contradictory forms.
Deconstructivist architecture, which is a system of thought that intervenes in the pure form, explodes it, robs it, but does not deny its existence (Esin, 1989), wants to emphasize the current indifference of society by increasing the tension between structural elements (Bayar, 1992).
Today, there is a pluralistic approach in architecture as opposed to the individualism attitude mentioned above. Architects have gone beyond the principle of simply expressing their ideas and current society with their structures such as the De Constructivism movement, and have developed a principle that aims to realize the concept of sustainability in material structures against the most important problems of the 21st century, the degradation of the ecosystem and the consumption of natural resources, since it was discussed at the 1st World Environment Conference in 1972.

3.5 Technological Developments on Sustainable Facades:
Since the first years of construction, people's primary expectations from building materials were to provide security and air conditioning. As a result of the researches, it has been determined that by understanding the relationship between facades and energy, different gains can be achieved not only by providing indoor comfort, but also by evaluating facades and temperature gains. (Table-1)(ESGİL & YAMAÇLI, 2023)

Table 1. Criteria and Sustainable Solutions in Relation of the Facade to Concepts (ESGİL & YAMAÇLI, 2023) (Edited by the author.)

	CRITERIA	ANSWERS
FACADE - TEMPERATURE RELATIONSHIP	Indoor temperature should be kept between 22°C and 27°C to ensure user comfort.	Use of shading and insulation elements on the facade that will protect the interior from the harmful effects of the sun and are resistant to all climatic conditions.
	Indoor temperature should be kept balanced and natural lighting	
	Solutions that are resistant to different climatic conditions should be produced.	
FACADE - ENERGY RELATIONSHIP	By keeping the indoor temperature balanced, the energy spent on heating-cooling systems should be saved.	Energy production should be provided from sources such as sunlight and wind energy.
	Energy production should be provided from sources such as sunlight and wind energy.	Installation of systems that can produce energy from sunlight and wind energy on the facade

With the need for raw materials and the climate change crisis that started with the Industrial Revolution, the term sustainability, used at the World Environment Conference in 1972, entered the field of architecture as well as other disciplines. The idea that precautions should be taken regarding the structures that are considered to be largely responsible for the carbon footprint has become widespread over time all over the world.
Kim and Rigdon (1998) group sustainable architecture principles into three groups: effective use of resources, life cycle design, and improving the quality of human life and aesthetics. While defining the effective use of resources as an important principle that starts with the production of building materials and continues throughout the building life cycle, reducing the use of non-renewable energy, life cycle design; is considered as design, construction, operation, maintenance, and demolition phases. It states that improving the quality of human life aims to increase and improve people's living standards, cultural, social, and physical environmental quality, as well as protecting human health and comfort (Kim and Rigdon, 1998, p.8).

Architects and engineers, who initially focused on improving insulation, later developed effective systems using renewable energy sources. Techniques that use energy efficiently are constantly being developed in direct proportion to the development of technology. The idea of living in harmony with nature rather than dominating it has become increasingly widespread within the built environment.

3.6. Developments in Sustainable Facades with Today's Technology

"The Autonomous House", made by Brenda and Robert Vale in 1975, is considered one of the first applications with ecological concerns. It takes a holistic approach from structure and material production to internal layout, aiming at low energy use. The idea of ecological design, whose first example was a housing design, was developed under six principles developed for ecological design in the book "Green Architecture" in 1991.

In 1992, William McDonough described the Hanover Principles for sustainable design. These principles are accepted by those who practice architecture based on ecological values and constitute a starting point for architects to create their approach principles.

1. Emphasizing the bringing together of human rights and nature in healthy, supportive, diverse, and sustainable design.
2. Identifying interdependence. Human design elements interact with the natural world at all scales, depending on it.
3. Respect for the relationship between spirit and matter.
4. To take responsibility in design decisions regarding human well-being, natural systems, and the interoperability of their truths.
5. To create objects that are valuable in the long term and safe for future generations.
6. Eliminating the concept of waste. Improving and evaluating the entire life cycle of products and processes, addressing the state of waste-free natural systems.
7. Trusting the natural flow of energy. Humanistic designs, like the living earth, must draw their creative forces from constant solar gain. Combining energy efficiently and safely for appropriate use.
8. Understanding the limits of design. Infinite inhumane creation and design is not the solution to all problems. Those who create and plan should practice humility in nature. Looking at nature as a model and mentor, rather than as an inconvenience to be escaped or controlled.
9. Seeking continuous improvement through the sharing of knowledge. To restore the integral relationship between natural processes and human activity and to encourage direct and open communication between colleagues, patrons, producers, and users engaged in long-term, sustainable conditions linked to moral responsibility. (McDonough, W.1992)

Nowadays, many studies are carried out to reduce the carbon footprint of buildings. So much so that, at the point where technology has come, it has been discovered that sustainability can only be achieved through smart facade designs, independent of the internal systems of the buildings.

Smart facades in general; It is defined as "an active and sensitive mediator between the external environment and the interior of the building, providing optimum interior comfort with minimum energy consumption" (Böke, Knaack & Hummerling, 2019)

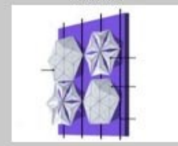
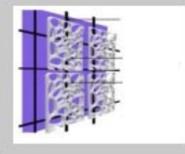
One of the most important factors that create smart facades is that the materials used are smart. We can divide smart materials into three groups; Smart Materials That Change Properties, Smart Materials That Exchange Energy, Smart Materials That Exchange Matter (Table-2)

Table 2. Advantages, disadvantages and applications of smart materials. (Shashi Bahl a et al., 2020)

Name of Smart Material	Advantages	Disadvantages	Applications
Piezoelectric	• High frequency response • Generate electrical signal on application of mechanical force • Structure is simple	• Working stroke is limited to several or ten micrometers limits its application in or as actuators • Wear and heat generation • Difficult to manufacture • Inchworm piezoelectric has complex structure	• Used in electronics devices such as transducers and sensors • Used at high temperature due to their high curie temperature • Micro positioning accuracy • Power gen in auto • Tyre pressure sensor • Knock sensor • Piezo fuel injectors
Magnetostrictive	• Higher energy density • Intrinsic robustness	• Magnetostrictive materials increases the complexity of the system • The accuracy of experimental reproduction is not enough	• Tuned vibration absorber • Damper • Engine mounting • sensors • Energy harvesting
Shape memory alloy	• They have elastic behavior • High fatigue failure Life • High damping capacities • High strength • Corrosion resistant	• Expensive • Temperature sensitive • High cycle fatigue • Complicated design and high weight	• Biocompatible • Aerospace • Robotics • Clothing and fashion industries
Electro-rheological fluid	• More stable system performance • Simple controller design • Act as power amplifier	• High Density • Fluid become thick after prolonged use need replacement	• Vibration dampers, Shock absorber • Clutches • Hydraulic valves
Magneto-rheological fluid	• Very little remnant magnetization • Higher permeability • Higher saturation magnetization	• High quality fluids are expensive • Settling of ferro particles can be problematic	• Vibration absorber • The deposition of iron particles • Sealing problems • Environmental contamination
Optical fibers	• Higher bandwidth support • High carrying capacity • Immunity to electromagnetic interference and tapping • Flexible • Optical fiber cables take up less space • Resistance to corrosive materials	• More expansive transmitter and receiver equipments • It cannot carry electrical power to operate terminal devices • Not suitable at higher optical powers • Installation is costly	• Advanced intrusion detection security systems • Optical chemical sensors and optical biosensors • Used to transmit power using a photovoltaic cell, as light guides in medical and other applications • Structural health monitoring, Spectroscopy, Imaging optics

With technological developments, technological materials used in buildings have not only reduced energy consumption by utilizing insulation but also with the use of facade materials, buildings can now create their energy.
Designed with this approach Al Bahar Towers in Abu Dhabi meets 5% of the building's total energy needs thanks to photovoltaic cells placed on the roof of the building. When taken together with the shading system, the building reduces CO_2 emissions by 1750 tons per year. Another example in Hamburg, Arup built the first “bioreactor facade”. Glass panels containing algae was placed on the sun-facing facades of the building. These panels, made of algae, meet the entire energy needs of the building and reduce carbon emissions by 6 tons per year. Manuel Gea Gonzalez Hospital, located in Mexico City, was designed not only as a covering material for the facade of the building but also as a system that can clean the air in its surroundings. (Table-3)

Table-3. Evaluation of Examples in the World According to Sustainability Criteria (ESGİL & YAMAÇLI, 2023) (Edited by the author.)

	Al Bahar Towers Facade 	BIQ Building Facade 	Hospital Facade 
Design Suitable for the Environment and Climate	Shading indoor comfort conditions	Shading indoor comfort conditions	Shading indoor comfort conditions
Conservation of Energy	Reducing the need for a cooling system with 80% shading, and reducing the need for artificial light with its ability to be turned on and off.	Meeting all the energy needs of the building with the algae inside the glass panels	–
Use of New and Renewable Energy Sources	The electrical needs of the shading system are provided by photovoltaic panels placed on the roof.	Use of biomass-renewable energy source	–
Waste Management	–	Reducing carbon emissions	- Reducing the building's carbon emissions -Cleaning air pollution caused by fossil fuel consumption and reducing damage to the environment
Use of Recycled Materials	–	Glass panels used on the facade	–

John MacLane Johansen's (b.1916-d.2012) works, which he describes as "nano-architecture" grows and multiplies starting from a seed, just like a plant in nature, and produces spaces in line with user needs with the designer's programming, are discussed. In light of the data obtained, it has been seen that futuristic architectural designs have a relationship with biomimetic concepts beyond the morphological approach and that Johansen's architectural approaches that imitate the functioning of nature at the molecular level are worth discussing with today's paradigms. (Çakmaklı & Selçuk, 2019)

3.7. Sustainable Facades with Future Technology

The term biomimicry was first coined by Janine M. Benyus, a science observer from Montana. This concept, which comes from the roots bios (life) and mimesis (to imitate), also means "imitating nature". (Çakmaklı & Selçuk, 2019)

Facade designs, which started to protect people from the conditions of nature, have come to the point of protecting and adapting to the ecological balance over time. As the concept of sustainability came to the fore and studies began to be conducted in this field, an attempt to build structures compatible with nature was arise. At this point, architects have foreseen becoming a part of imitating this ecosystem as a way of being compatible with the ecosystem in nature. In this context, the first examples have begun to be created in the field of "Biomimetic Architecture", which is one of the two most prominent terms for the future.

The Lilypad project is an eco-friendly floating city that envisages sheltering 50,000 people. Designed by Vincent Callebaut to be presented at the “Oceans 2008” conference. The project, which envisages zero carbon emissions, will be able to create all the energy people need with titanium dioxide facades.

As we can see upon examining the Lilypad project, another term we encounter in the architecture of the future is "nano-materials".

Figure 1. Images from the Lilypad project (Vincent Callebaut Architectures, 2017)

Along with nanotechnology, developments in other branches of science such as software, robotics, and genetics will take architecture to a different dimension from its current patterns. Even the building texture can change between solid, liquid, and gaseous states of matter at will, with software applied to nanomaterials, and facades that are sometimes opaque and sometimes transparent can be obtained. In short, everything that is important today in architecture will lose its meaning, and humanity will be introduced to a completely different and completely organic architecture (Çakmaklı & Selçuk, 2019).

4. Discussions

In this section, the buildings that left their mark on their periods mentioned in the article are compared in the context of sustainability criteria in the table below (Table 4).

Table 4. Comparison of the Examined Buildings in the Context of Sustainability Criteria

	Çatalhöyük	Crystal Palace	The Autonomous House	Al Bahar Towers Facade	BIQ Building Facade	Manuel Gea Gonzalez Hospital Facade	Lilypad
Design Suitable for the Environment and Climate	-Climatic adaptation: The design of the houses is made to adapt to the variable climate of central Anatolia. Additionally, there were hearths inside the houses for protection during the winter months. -Building materials: Materials abundant in the region were preferred in the construction of houses. -Topographic harmony: Çatalhöyük's location was built on a high area to protect it from floods and other natural hazards.	-Light Transmission: The fact that the Crystal Palace is covered with glass sheets allows plenty of natural light to enter the interior spaces. - Location of the Building: A large area such as Hyde Park, where the building is located, ensures the protection of the natural environment and the best use of the landscape.	-Using a giant greenhouse to keep the house warm during the British winter provides effective heating in cold climate conditions. -Heat Insulation: Heat loss is minimized by using triple-glazed windows. -Use of Solar Energy: Electricity is produced by using solar panels at home. -Water Management: Collecting rainwater and using it to meet water needs stands out as an environmentally friendly water management strategy.	Shading indoorcomfort conditions	Shading indoorcomfort conditions	Shading indoorcomfort conditions	Surfaces Covered with Green Plants Zero Carbon Emission Ecological balance Renewable energy sources Use of Ecological Technology
Conservation of Energy	Natural heating and lighting: the design of the houses is planned to make the best use of sunlight.	Natural Lighting: A structure with large glass surfaces, such as the Crystal Palace, allows natural light to enter the interior spaces.	-Use of Solar Energy -Thermal insulation -Natural Heating and Cooling -Waste Management and Recycling: Household wastewater is treated and recycled	Reducing the needfor a cooling system with80% shading, andreducing the need forartificial light with its abilityto be	Meeting all theenergy needs of thebuilding with thealgae inside the glass panels	-	Lilypad is built with energy efficient design principles. Energy consumption is minimized by using technologies such as insulation materials,

			through a composting toilet. This prevents waste of water and other resources and reduces energy-related side effects.	turned on and off.			energy-saving lighting and heating systems. Thus, the energy used is used efficiently. -Natural Lighting and Ventilation
Use of New and Renewable Energy Sources	Biomass: A simple heat source could be provided by burning wood and plant waste.	-	-Wind Energy: In some cases, wind turbines can also be used. These turbines meet the energy needs of the house by converting wind energy into electricity.	The electrical needsof the shadingsystem are provided byphotovoltaic panelsplaced on the roof.	Use of biomass-renewable energy source	-	Solar Energy Wind Energy Tidal Energy Biomass Energy Water Purification with Solar and Wind Energy
Waste Management	Combustible Waste: Çatalhöyük residents generally disposed of used charcoal or other flammable waste by burning.	-	Compost Toilet Recycle Zero Waste Target Natural Waste Management Environmentally Safe Waste Disposal	-	Reducing carbonemissions	-Cleaning air pollution caused by fossil fuel consumption and reducing damage to the environment - Reducing thebuilding's carbon emissions	Waste Reduction and Resource Use: During the design phase of the project, strategies are determined to minimize waste generation. This is achieved by focusing on material selection, production processes and consumption habits. Wastewater Management: Proper treatment and recovery of wastewater is one of the project's waste management strategies.
Use of Recycled Materials	Stone and Adobe: Stones and adobe used as construction materials could be reused during the demolition or renovation of old buildings. Materials from a destroyed house could be used to build a new structure or repair an existing one. Metal Items: Çatalhöyük residents could recycle metal items by recasting or reshaping them. For example, an old metal container or tool could be melted and cast to be reused for another purpose. Natural Materials: Natural materials such as plant fibers, leather and	-	-Recycled Construction Materials: The use of recycled materials in home construction has been encouraged. -Recycled Insulation Materials: Recycled materials were used as insulation materials in the house. -Recycled Interior Decoration Materials: Recycled materials were preferred in furniture, carpets, flooring and other decorative materials used in the house. -Recycled Water and Electrical Equipment: Water and electrical equipment used in the home are made from recycled materials.	-	Glass panels usedon the facade	-	Material Selection Real-Time Recycling: During the construction process, workers and construction crews can encourage the use of recycled materials. For example, during a construction or renovation work, waste materials can be collected and sent to recycling facilities. Product Recycling Innovation and Technology

	bone could be repurposed to recycle or reuse waste. For example, the skin of an animal could be used to make clothes or bags, and the bones could be used to make tools.						

In Çatalhöyük Neolithic period settlements, concepts such as complex energy systems, use of recycled materials, or waste management were not used as they are today. However, people living in this period generally used simple methods to protect natural resources, and even if these methods were not aimed at sustainability, it was possible to meet basic needs and make life easier with the energy resources obtained from local resources.
The environment and climate in which Crystal Palace is located are one of the important factors taken into consideration in its design. London, where the building is located, has a typically temperate oceanic climate, meaning that the weather is generally mild and rainy. The design was made considering these environmental and climatic factors. The building has no known initiatives in terms of the Use of New and Renewable Energy Sources, Waste Management, Use of Recycled Materials.
The Autonomous House project includes design principles suitable for the environment and climatic conditions. Completed in 1993, this house aims to make the most of environmental elements. A giant greenhouse is used to warm the house by trapping solar heat, and triple-glazed windows reduce heat loss. Electricity is provided through photovoltaic arrays and the excess is exported to the national grid. Water is used by collecting rainwater and treating wastewater through a composting toilet.
Al Bahar Towers In summary, it is aimed to reduce the need for a cooling system and reduce the use of artificial light by providing 80% shading to ensure indoor comfort conditions. The electricity needs of the shading system are provided by photovoltaic panels placed on the roof.
To provide indoor comfort conditions, BIQ Building aims to meet the entire energy need of the building with the algae inside the glass panels. This involves the use of algae, a biomass–renewable energy source. Additionally, it is aimed at reducing carbon emissions. For this system, glass panels used on the facade are used.
Manuel Gea Gonzalez Hospital Facade aims to clean air pollution caused by fossil fuel consumption and reduce damage to the environment. Additionally, it is aimed to reduce the carbon emissions of the building.
The Lilypad project was built with energy-efficient design principles, and the energy consumption is minimized with technologies such as insulation materials, energy-saving lighting, and heating systems. An environmentally friendly approach is adopted by using ecological technologies such as natural lighting and ventilation, solar energy, wind energy, tidal energy, biomass energy, and water purification. In the project design, strategies are determined to minimize waste production, and waste management is provided. The use of recycled materials is encouraged and recycling activities are carried out during the construction process. In this way, the use of recyclable materials during construction activities is encouraged and emphasis is placed on product recycling. An environmentally friendly structure is created through the use of innovation and technology.

5. Conclusions

It aims to contribute to the literature by providing enlightening information about how this structure changes over time depending on the characteristics of facade designs and how technological breakthroughs shape the evolution of sustainable facades. Study of different architectural styles and their parts through financial analysis, how interests, technical developments, and social requirements make the façade design open to change.
Distributed traditionally like adobe, stone, and wood; The contemporary transition of technologies such as iron, glass, and concrete, largely triggered by the Industrial Revolution, is one of the main consequences of distribution. Even though the natural features in the environment and an environmentally friendly approach were achieved in the in the early days of mankind , material possibilities were limited Just as mankind has combined and dried materials such as soil and straw to obtain the first composite material, mudbrick, developments towards the sustainability of facade design materials continue.Carbon emissions due to construction have increased to high levels due to the distribution of fabricated production materials all over the world, which started with the Industrial Revolution.
On the other hand these improvements not only made it easier to build larger, more complex structures but also made the existence of the creative facades possible.

Examining environmentally friendly facade solutions highlights how important their prevalence has become for modern architectural practices. The- architects use the latest technologies to reduce temperatures and increase the comfort of building occupants. This technology can range from active systems such as photovoltaic panels and algae-based bioreactors to passive design methods such as enhanced flexibility.
Additionally, hardware technologies (especially biomimicry and nanomaterials) offer an interesting look at how their properties, adaptability to the nature of architecture, and difference can be mimicked. The Lilypad project is an exemplary example that integrates produced products and ecological conditions to build sustainable living spaces. The idea aims to achieve zero carbon emissions and uses titanium dioxide facades.
Although these developments have the potential to reduce fragility, it is also beneficial to be able to choose whether it is more ecological and economical to do so.For sustainable façade solutions to be inclusive and equitable, issues such as cost, accessibility, and scalability need to be taken into account.
The study concludes by highlighting the complex components that exist between sustainable building materials, technological innovation, and façade design. By following the trajectory of facades and analyzing their current and present condition, architects can embrace the potential to transform exchange technologies and draw inspiration from the past to create buildings that balance the environment with humane solutions.
The concept of the facade, from the earliest times when human beings began to build, has not only been a part of the design process of the building but also reveals the cultural, social, economic, and technological reality of the society. When viewed with this awareness, the material used in façade design is as important as the design language used.
The concept of sustainability, which entered our lives with the need for raw materials that started with the Industrial Revolution and the climate crisis, has entered every field of technology, as well as building technology. It is an undeniable fact that major innovations are required to ensure the use and application of sustainable materials.
In the second chapter, the historical development of the facade was examined and it is seen that since the Neolithic age, people started to work on improving the material. The Adobe material used in that period is the biggest example of this. Until the 19th century, people continued to produce new materials, and with the use of these materials, not only new technologies but also new architectural styles were formed.
A new system has been introduced to the buildings by building Kristal Palace with pre-fabricated construction parts. Thanks to this new system, not only building construction times have been shortened but also costs have been reduced.
Even though the industrialization in the construction sector that came with this new system accelerated the construction time of the buildings, it increased the carbon footprint created by the buildings, making the construction industry one of the major items in the climate crisis. The term sustainability, used at the World Environment Conference in 1972, entered the field of architecture as well as other disciplines. The idea that precautions should be taken regarding the structures that are considered to be largely responsible for the carbon footprint has become widespread over time all over the world.
Technological developments in sustainable facades are examined. Smart facade systems used in today's technologies continue to develop and transform. Thanks to bioreactor façade systems and algae, Al Bahar Towers reduce CO2 emissions by 1750 tons per year.
It is anticipated that eco-friendly floating cities will be created with nano-materials in the future. The Lilypad project, one of the first examples in the field of biomimetic architecture, is considered to be one of the first examples of this.
In this study, the effect of the material on the facade design and how the concept of sustainability participates in the architectural process are examined. The structures built with today's technology and the technologies foreseen in the future were evaluated.
When considered on a Turkish scale, determining national standards will be a long and costly process. It is not easy for companies operating in smart facade systems to suddenly switch to such an application. Companies may need to invest and change their production approach. However, such a change will be very profitable in the long run, not only will it make a great contribution to the country's economy, but it will also be a solution to the climate crisis.
Such a change can occur with legal regulations and credit and incentive systems to be given to commercial companies. What is more important than the economic dimension is to raise awareness and convince architects and all units operating in the construction sector how important and necessary this issue is.

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Conflict of Interests
The Author(s) declare(s) that there is no conflict of interest.

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