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EXAMPLES OF ADAPTIVE MODULE VARIATIONS FOR ADAPTABLE BUILDING SHELL DESIGN[1-2]

UYARLANABİLİR BİNA KABUĞU TASARIMI İÇİN ADAPTİF MODÜL VARYASYONLARIN ÖRNEKLER ÜZERİNDEN İNCELENMESİ

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Abstract: Aim: The aim of the research is to obtain numerical data by examining the types of adaptation, adaptation components, and adaptation pattern knowledge based on widely known building examples worldwide that have been frequently studied in the literature in relation to buildings designed with adaptive building envelopes. Through the obtained numerical data, the aim is to analyze which parameters are preferred more while designing an adaptive module.

Method: Adaptation type, component, pattern and method parameters were examined by tracing method on the examined building samples. The obtained numerical data were statistically evaluated with the regression analysis method, and the percentages were found and compared.

Results: As the adaptation type of the modules of the structures examined in the study, 70% were found to be mobile while 30% were fixed. The usage rates of the adaptation components of the modules of the projects were found on the facade, the shell, the facade + the shell and the structure + the shell. It has been observed that the most common geometric and traditional patterns are used among the adaptation patterns.

Conclusion: When adaptation methods were examined, it was determined that the most common features in the examples were being sensitive to solar movement, having light level control, being able to control shading and indoor spaces, contributing to passive systems, and being adaptable to climate. The preference for these criteria varies according to the conditions. This study aims to shed light on parameter selection for future adaptive designs and studies.

Keywords: Building Shell, Adaptive Architecture, Adaptive Facade Design, Adaptive Module Variations

Öz: Amaç: Araştırmanın amacı adaptif bina kabuğu ile tasarlanmış olan literatürde makalelerde sıkça incelenen örneklerden seçilmiş olan, dünya genelinde yaygın olarak bilinen, bina örnekleri üzerinden adaptasyon tipleri, adaptasyon birleşenleri ve adaptasyon desen bilgisi incelenerek sayısal veriler elde etmektir. Elde edilen sayısal veriler aracılığıyla adaptif bir modül tasarlanırken hangi parametrelerin daha fazla tercih edildiğinin analiz edilebilmesi hedeflenmektedir.

Yöntem: İncelenen yapı örnekleri üzerinden iz sürme yöntemi ile adaptasyon tip, birleşen, desen ve metot parametreleri irdelenmiştir. Elde edilen sayısal veriler istatiksel olarak regresyon analiz yöntemi ile değerlendirilerek yüzde oranları bulunup karşılaştırmaya gidilmiştir.

Bulgular: Çalışmada incelenen yapıların modül örneklerinin adaptasyon tipi olarak %70'inin hareketli iken %30'unun sabit olduğu görülmüştür. Projelerin modüllerinin adaptasyon birleşenlerinin cephede, kabukta, cephe + kabukta ve strüktür + kabukta kullanım oranları bulunmuştur. Adaptasyon desenlerinden en sık geometrik ve geleneksel desenin kullanıldığı görülmüştür.

Sonuç: Adaptasyon metotları incelendiğinde; güneş hareketine duyarlı olma, ışık seviyesi kontrolü özellikli, gölgeleme- iç mekân kontrolü yapabilme, pasif sistemlere katkı sağlayabilme ve iklime duyarlı uyarlanabilir olma kriterlerinin örneklerde en çok yer alan özellikler olduğu tespit edilmiştir. Bu kriterlerin tercih edilme durumu koşullara göre değişkenlik göstermektedir. Bu çalışma ileride yapılacak olan adaptif tasarımlara ve çalışmalara parametre seçimi için ışık tutmayı hedeflemektedir.

Anahtar Kelimeler: Bina Kabuğu, Uyarlanabilir Mimari, Adaptif Cephe Tasarımı, Adaptif Modül Varyasyonları

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[2] Çalışma, araştırma ve yayın etiğine uygun olarak hazırlanmıştır. Çalışmada herhangi bir intihale rastlanmamış olup dergi kapsamında istenen %20 alıntı oranına uygun olarak hazırlandığı bu yönlerden makalenin tüm sorumluluğu ile bilgilerin doğruluğu ilgili yazar(lar) tarafından kabul edilmiştir. İşbu makalenin her türlü telif ve sair diğer hakları açık erişim olmak üzere yazar(lar) tarafından dergiye devredilmiştir. "The study was prepared in accordance with research and publication ethics. No plagiarism was found in the study and it was prepared in accordance with the 20% citation rate required within the scope of the journal, and in these respects, the full responsibility of the article and the accuracy of the information has been accepted by the relevant author(s). All copyright and other rights of this article have been transferred to the journal by the author(s) as open access."

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INTRODUCTION

''It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change.''

-Charles Darwin

All the environmental problems in the world are related to ecology. All beings living in the world, by nature, want to meet their basic needs and senses from the data of nature. In this context, space; geographical region character and features are expressed with all cultural and physical ecological connections, flows, cycles and networks (Senem & Arıdağ, 2016). Today, both national and global civil and public authorities take measures to reduce energy consumption, control and minimize negative effects on the environment (COM, 2006; Kibert, 2002; Lee & Yik, 2002).

While the need for energy increases with the development of technology, energy resources are decreasing day by day. In this context, the energy efficiency to be provided in buildings is gaining importance day by day. To ensure sustainability, it is necessary to design structures that are sensitive to the environment and consume less energy, which are an indispensable element of human life. For this, energy efficiency should be accepted as a basic design input in buildings. Energy, which is indispensable for the continuation of vital activities, will be one of the most important legacies to be transferred to future societies if it is used efficiently (Hatipler Çibik & Umaroğulları, 2019). Even though energy efficiency was not a common term before the 20th century as it is nowadays, people have found ways to use and transform natural mechanisms to improve living conditions since ancient times (Ionescu et al., 2015).

For people to maintain their current life comfort, the energy they need must also continue. In this context, it has become one of the most important goals for people to use energy efficiently, to benefit more from sustainable resources, and to transfer our natural environment to future generations (Hatipler Çibik & Umaroğulları, 2019). In addition to all the environmental problems that are increasingly encountered, the need to reduce the energy consumed by the buildings reveals the idea of performance-based design in architecture, which can be defined as a design optimization process with any imposed design criteria and any imposed design criteria (Kolarevic, 2005).

The construction industry is responsible for 50% of the energy consumed in the world, 42% of the water consumed, 50% of the greenhouse gases, 40% of the pollution in drinking water and 24% of the air pollution. Considering these figures, the important role of the construction sector in ensuring sustainability is understood. To prevent these problems, it is necessary to reduce the use of water and energy, waste, and pollution in the construction sector; it is necessary to increase the efficiency of building materials and the comfort of the building (Şermet & Özyavuz, 2017).

Buildings constitute a large part of the world's energy consumption, which causes the greenhouse effect and global warming to increase. Energy efficient building design has become imperative for energy conservation,

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reducing emissions, and improving quality of life. The first studies on the energy efficiency of buildings (Johnson et al. 1984; Steadman & Brown, 1987) focus on the investigation of certain parameters that affect the energy performance of buildings. Energy efficient building design studies have attracted the attention of researchers and designers. Thanks to the climate-compatible measures in the buildings, the passage of factors such as heat, light, sound, etc. to the indoor environment can be prevented and thus the additional energy consumption that may arise can be reduced to a minimum (Ngo, 2019; Y. Guo et al., 2018; Chou & Bui, 2014).

There are many lessons to be learned from nature for designers who can observe and understand nature. Researchers trying to understand the relationship between form, structure, and material, especially in nature, can use mathematics, computer technologies and analogy methods as a tool and increase their communication with other disciplines and work out their own systems in the best way with the important clues they get from there (Senem & Arıdağ, 2016). Every space is associated with environmental and climatic conditions, and humanity must use architecture to create livable spaces (Senem & Arıdağ, 2016).

In our world where the places we live in are constantly changing, environmental factors play a big role in the mentioned change. "Adaptive architecture" enables the user in the building to live comfortably and under ideal conditions by effectively shaping the architecture of environmental factors. In addition to these, "adaptive architecture" is also important in terms of environmental protection and sustainability. The concept of adaptive for facades and building envelopes was first used in the early 1980s. The shell around the building assumes a function that surrounds and preserves the building. (Yerli, 2016). An adaptive building is defined as a building that can evaluate and respond to indoor and outdoor conditions, change itself or activate other systems in the building. Environmental changes in the life processes of buildings necessitate the adaptation of facades and building envelopes to them. Climatic changes appear as the most decisive and most effective examples of environmental factors. Especially today, buildings and users are exposed to uncertain climatic conditions due to global warming. The compatibility of the building with the environment is defined as the adaptation of the building envelope or facades to the natural environment or artificial environmental conditions created later by acting together with some limitations and natural factors. Adaptive facades are defined as facades that allow changes in the building envelope and the creation of new aesthetic constructs with the help of various sensors containing mechanical or electronic systems that can act in accordance with environmental conditions. The fact that the building envelopes built before the 20th century are not dynamic enough and cannot adapt to environmental influences reduce the comfort of life in these buildings, while at the same time reducing the life of the buildings and increasing the building operating costs. Today, with the development of technology, designing movable facades and building shells ensures that such incompatibilities are reduced to a lesser extent and plays an important role in solving the problems that arise due to the building's not being dynamic.

In today's information society, which is formed by the increasing use of information technologies, it is observed that design culture and therefore architecture gains a different dimension by using new design methods developed under the name of computational design (Palabıyık & Demircan, 2020). In today's world, where computers and software are easily accessible, computational technologies exist in almost every aspect of our lives, changing our thinking system and methods. The development of computational technologies and their relationship with architecture made it inevitable to change in architectural thinking and solution methods. Finally, seeing the contribution of problem solving and computational tools such as computers to architectural solutions has made it possible to use the computer as a design partner that produces answers to the design problem, beyond being just a presentation tool that replaces paper and pencil. It can be said that the most important paradigm shift in architecture in recent years has been the application of computational technologies in design and the associated changes in form, design thinking and design processes. In this context, computing technologies have made design a process that is a part of many other organizational processes, and the perceptual and cognitive aspects of these processes are emphasized for the designer's research (Palabıyık & Demircan, 2020).

Computational design approaches change the representation of architectural design in the digital environment from geometrical 'symbols' to geometric 'relationships'. Therefore, the representation of the architectural product by parameters, beyond representing the geometric (dimensional, formal) features of its form, also represents its performance, that is, the behavior of the form, which covers a wide range from the material and element scale of the design product to the space and structure, from the functional and environmental performance of the space to its visual performance. (Palabıyık & Demircan, 2020). Today, considerable progress has been made in transforming analytical processes into computational models. At the point of using computational technologies, it is seen that the ideas and computational principles are not only limited to the articulation of architectural form studies, but also affect the design action and the design methods used in the process in a wider framework (in terms of evaluation and simulation of design definitions). Advances in computational technologies and algorithms allow these computations to increase in size and complexity, making many designs possible today that were unimaginable a few years ago (Kilian, 2012). With the help of these technologies, it has been made possible for the places we live to change depending on the variability of environmental factors.

In our world, where global warming affects the world and there is a constant climatic variation, providing visual, thermal, and auditory comfort in buildings is one of the most important problems of architecture.

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Today, the discipline of architecture has moved beyond its own field and can cooperate with different science, engineering, and social fields more often than before. In this way, adaptive facades, which can change based on performance in line with environmental factors, have become an important research area in terms of increasing the living comfort of the building, as well as making the building sustainable, reducing operating costs and extending the life of the building.

Adaptive elements can be designed to respond to the external environment, or they can be designed to respond to the indoor environment to increase the interior comfort level and control energy consumption. Although adaptive structures are defined as flexible, interactive, or dynamic, they adopt the idea that architecture is adaptive rather than a static work, and generally emphasize computer-aided adaptation (Orhon, 2016).

The potential application areas of adaptive facades and building envelopes are increasing in parallel with today's developments. The most important factors in increasing the potential of adaptive facades and building envelopes can be listed as the development of decision support mechanisms, the development of the interfaces of the programs that help material technology, design, and production.

While designing the module variations used in the adaptive façade and building envelopes, which ensure the adaptability of the building, it is important that the building be designed in line with whichever parameters the building will serve. For this reason, it is important to consider the module variations used in adaptive façades and building envelopes in this study, in terms of revealing what should be considered when designing an adaptable structure.

AIM

The purpose of the article is to obtain numerical data by examining the types of adaptation, adaptation components, and adaptation patterns based on widely known building examples worldwide that have been frequently studied in the literature in relation to buildings designed with adaptive building envelopes and facades. Additionally, determining the usage rates of adaptation methods is also one of the main objectives. By analyzing which parameters are preferred more while designing an adaptive module through the obtained numerical data, this study aims to provide preliminary information for future studies.

SCOPE

As part of the study, a literature review on adaptable structures was conducted. Then, relevant research was carried out on building examples that are frequently examined in the literature and designed with adaptable building envelope and adaptable façade, which were selected for fieldwork. Based on these researches, building information labels were created. The tracking method was used to examine the parameters of adaptation type, component, pattern, and method on the selected building examples. The obtained numerical data was statistically evaluated through regression analysis and compared by finding percentages.

METHOD OF THE RESEARCH

In the study, after the necessary literature review about adaptable buildings, building information labels were created by making a relevant research on building samples, which are widely known throughout the world, selected from the examples frequently examined in the literature designed with adaptive building envelope and adaptive facade. The fit types and parameters of the components of the selected building samples were analyzed. In addition, the pattern and method parameters of the examined adaptive module variations were also examined. The data that emerged with the monitoring method, which is a qualitative method, were transformed into quantitative data with statistical evaluations. Necessary graphics, tables and analysis templates were created to compare the analysis results and to reach general conclusions to be evaluated within the scope of the study. Finally, the statistical relationship obtained as a result of the analyzes was examined with the regression analysis method and the research was completed.

THE PROBLEM OF THE RESEARCH

Climate change and its effects on the environment are a visible reality, and the necessity of adapting architecture to change, which is one of the areas most affected by this change, emerges as a problem. Designing buildings and building elements that can adapt to changing climatic conditions and the environment is also important in terms of environmental protection and sustainability. Today, when changing climatic design parameters are observed, adaptive designs based on performance are gaining more and more importance. For this reason, it will be useful to evaluate the design methods of module variations, which are important in the creation of adaptable building envelopes and facades, and to make compatible choices in terms of the method suitable for the project. The problem of the study is to examine the parameters used while making adaptive designs and to investigate what is taken into account when determining the design parameter preferences.

THEORETICAL FRAMEWORK

Today, the discipline of architecture cooperates with many different disciplines, and many different methods are used in the design process. Performance-based adaptive architecture is one of the most frequently used of these methods today. The fact that architectural subjects depend on many variables has revealed the approach of examining these subjects primarily with science, engineering, and social fields. Reactions based on performance in line with environmental factors enable building envelopes and facades to change and create different morphologies. The response to an environmental influence offers interesting opportunities for performance. The sun is the most decisive factor in terms of both thermal comfort and visual comfort (light balance). Solar control systems have an important place in the building envelopes, based on which buildings can adapt to environmental conditions and provide the necessary comfort conditions. The performance-based adaptive building envelope model, which can change itself according to the sun, contributes to the

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design of buildings that can offer more comfortable spaces for less cost to the environment and the building user. Looking at today's energy use analyses, building envelopes contribute greatly to this use.

Samir and Shahin (2019) stated in their study that recently developed high-performance shells and facades have greatly led to the emergence of innovative manufacturers integrating real-time environmental response, advanced materials, dynamic automation with embedded microprocessors, wireless sensors and actuators, and design techniques for manufacturing. The paper discusses the design of three strategies, integrating advanced energy performance and architectural innovation, used in the construction of adaptive building envelopes for high-rise buildings to control physical environmental factors (heat, light, sounds). The aim of the study is to explain new conceptual ways of designing adaptive building envelopes for multi-story buildings that respond to environmental changes in the surrounding climate of different parts of the world and how such adaptive shells can be used. First, the necessary literature studies on the properties of high-performance facades were made, and then the current examples and ideas of adaptive shells were presented and analyzed. Three adaptive building envelope applications were examined and analyzed within the scope of the field study and their effects on energy savings of buildings were observed (Samir & Shahin, 2019).

Jayathissa et al. (2018), in their study examining the energy performance of PV modules as adaptive building shading systems, present the information that shading systems improve building energy performance by controlling solar energy gains and natural lighting. A sample selected in the study was modeled in the Rhino / Grasshopper environment, and the building energy analysis was done via DIVA / EnergyPlus. From this simulation, the optimum hourly position and orientation of the PV panels has been determined not only for the optimum energy but also for the overall interior space balance of the analyzed room (Jayathissa et al., 2018).

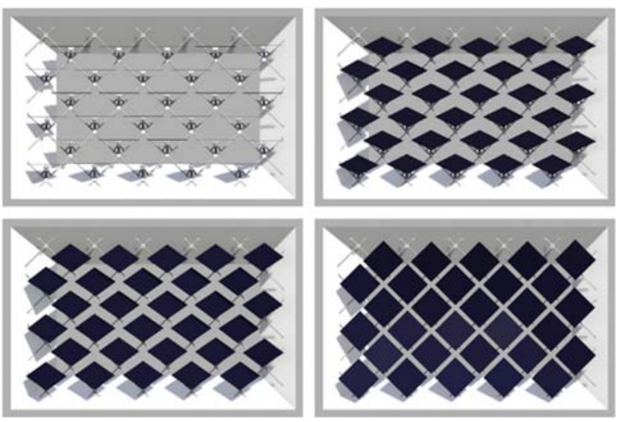

Figure 1. The Adaptive Solar Facade Existing in Varying States (Jayathissa et al., 2018)

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In his study, Harry (2016) emphasized that the building envelope has an important role in providing indoor comfort and building energy efficiency for building occupants. As a dynamic, active, and integrated solution, Dynamic Adaptive Building Shell (DABE) is the most promising and innovative strategy for the building envelope of tomorrow, capable of achieving optimum thermal performance, using energy from renewable sources, and integrating active elements and systems. According to the detailed studies, the characteristics, enabling technologies and general motivations that enable DABE to progress are discussed. Despite its positive aspects, the study reveals that the concept of Dynamic Adaptive Building Shell 'DABE' is not well implemented yet and needs much more research (Harry, 2016).

Romano et al. conducted a study in which the definitions of the adaptive facade were analyzed, examples were examined, and the latest terms in this field were examined in their article. In the study, it is mentioned that it was Frei Otto who first defined adaptive architecture as a system that can change shape, location, use or width. While defining adaptive architecture, Frei Otto drew attention to the fact that it can be moved, mobile and practical with the help of technological systems. Adaptable facades and skins consist of multifunctional systems that can change their functions, properties, or behavior over time between indoor and outdoor spaces to improve building performance. Adaptive shell types can be adapted to weather conditions and thus both provide energy savings and meet user needs. In the study, examples of adaptive structures designed by being inspired by nature, animals and the environment are also included (Romano et al., 2018).

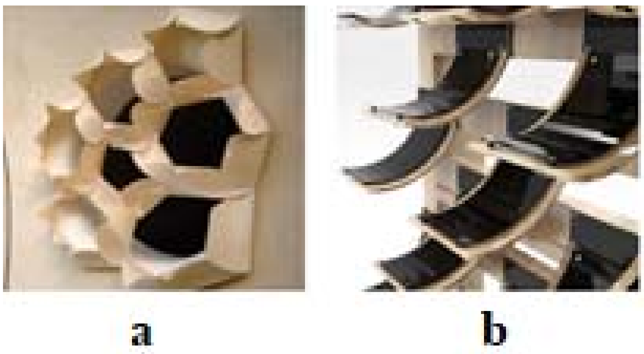

Figure 2. Examples of Adaptive Shells Designed with Bio-Inspiration: a) Hygroscope, Centre Pompidou, Paris (FR), b) BIPV Adaptive Flakes, Milan (IT), (Romano et al., 2018)

Berkmen and Altın examine adaptive facades and working systems that use solar and wind energy from renewable energy sources in their studies. For this, first of all, adaptive facades are explained by considering the concept of adaptability, then the use of adaptive facades is analyzed by examining the sun and wind adaptive facade examples. The entire façade of the 'CJ CheilJedang Research and Development Center' building, which he

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examined within the scope of examples of façades exposed to the sun, is surrounded by a foldable façade system consisting of perforated strips that can be opened and closed when desired. Thanks to this moving façade, while the research laboratories, which is one of the usage areas of the building, are protected from the glare of daylight, natural light enters the space simultaneously. To open or close the façade system, pantographic elements (a series of rods attached to each other by movable joints) were used, and these elements were placed regularly around the building's perimeter. A fixed connection is established with the primary and secondary elements, and both fixed and sliding connections are established with the tertiary elements.

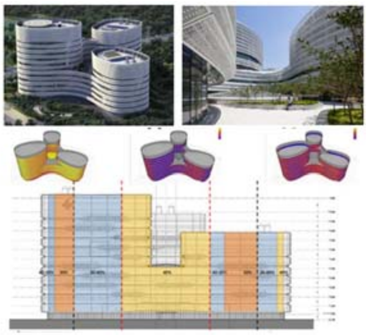

Figure 3. CJ CheilJedang Research and Development Center, Yazdani Studio and Cannon Design, 2016, Seul, South Korea (Berkmen & Altın, 2019)

Literature Search for Adaptive Module Variations

In their study, Khelil et al. (2020) designed the designers' building facades in hot dry climate regions to provide energy mysticism and especially as a proposal for the design of sun-sensitive shading systems. A module was designed to be used as a façade shading element, with reference to the opening and closing of the purpurea flower with a biomimetic approach (Khelil et al., 2020)

Figure 4. Facade Shading Element Based on the Opening and Closing of Purpurea Flower (Khelil et al., 2020)

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In this study, Brzezicki (2018) aimed to develop new design strategies with the help of computer aided design tools to produce module alternatives in the façade base based on the inclined grid system. Variations were produced with the help of periodic tiles and voronoi diagrams (Brzezicki, 2018).

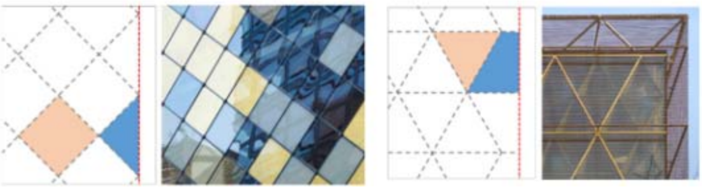

Figure 5. Square and Triangle Variations - Periodic Tiles and Easy Replacing Method (Brzezicki, 2018)

Mirkazemi and Mousavi (2020) examined the use of geometric patterns in nature in adaptive shell designs. They analyzed fractal and repetitive patterns in nature on the examples of facades (Mirkazemi & Mousavi, 2020).

Figure 6. Structure Based on Fractal Geometry (Mirkazemi & Mousavi, 2020)

Elkhatieb and Sharples (2016) examined the issue of parametric façade module proposal for climate-compatible building envelopes for office buildings in Egypt, which cares about daylight. The module pattern was inspired by traditional Egyptian claustra and mashrabiya (Elkhatieb & Sharples, 2016).

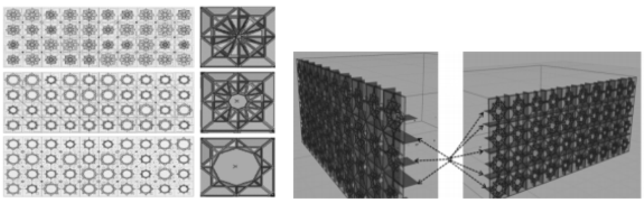

Figure 7. Variation Trial for Facade Cladding from Egyptian Traditional Patterns (Elkhatieb & Sharples, 2016)

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RESULTS

It is important for the protection and sustainability of the environment to design structures and building elements that can be adapted to changing climatic conditions and the environment so that architecture, which is one of the areas where climate change and its impact on the environment are most affected, can adapt to change. For this reason, evaluating the design methods of the module variations, which are important in the creation of adaptive building envelopes and facades, and making the right choices in terms of method in accordance with the project are preliminary data for the buildings to be built in the future.

By evaluating the suitability of the parameters used in the design comparatively with different parameters, sample structures were selected to be examined within the scope of the study to determine what the right choices are while making adaptive designs. After the necessary literature review on adaptive structures, sample structures were selected from the buildings designed with adaptive building envelope and adaptive facade, which are the most striking in the literature. First, a table containing the building information tags of the 10 buildings to be examined was created.

Table 1. Building Information Tag

Build No.	Ref.	Module	Building Photo	Building Envelope (Schematic)	Project Name / Year / Location	Building Type
1	(Elwazer & Ko, 2012)[1] (designboom, 2022)[2]				Al Bahr Towers / 2012 / United Arab Emirates, Abu Dhabi.	Office Building

[1]https://edition.cnn.com/2012/11/18/world/meast/ancient-screen-design-in-abu-dhabi/index.html
[2]https://www.designboom.com/architecture/aedas-al-bahar-towers/

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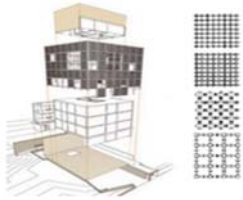
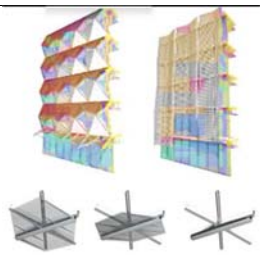
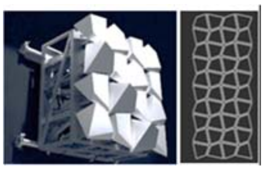
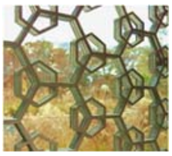
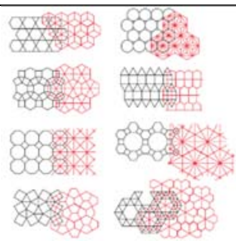
2	(Coelho & Maes, 2009)				Arab World Institute / 1987 / Paris, France.	Institute Building
3	(Loonen, 2010)				City of Justice / 2011 / Madrid, Spain.	Justice Building
4	(Loonen, 2010) (Moreforless, 2016)[4]				Flare Facade Building / 2008 / Berlin, Germany.	Office Building
5	(Decanteddesign, 2015)[5] (Azahner, 2022)[6]				Suny Stony Brook Simons Center for Geometry and Physics Lobby / 2010 / New York, USA.	Institute Building

[3]https://yimingsu.files.wordpress.com/2010/12/arab-institute-jean-nouvel.pdf
[4]http://moremorexless.blogspot.com/2016/05/kinetic-mbient-reflection-membrane.html
[5]https://decanteddesign.com/2015/03/31/adaptive-building-wall-roof-shading-systems-from-adi-adaptive-building-initiative-are-not-new-but-this-is-a-little-compilation-see-blogroll-for-a-link-to-the-adi-site/
[6]https://www.azahner.com/works/stony-brook/
[7]https://mathworld.wolfram.com/DualTessellation.html

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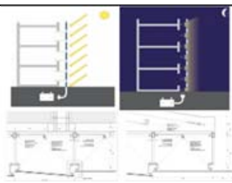
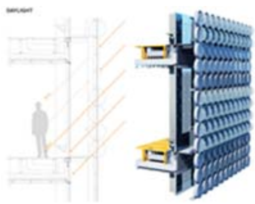
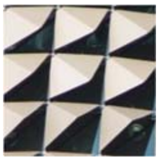
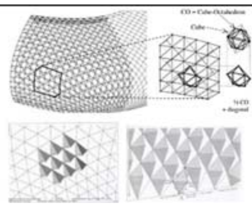
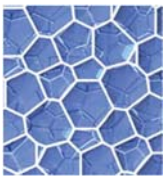
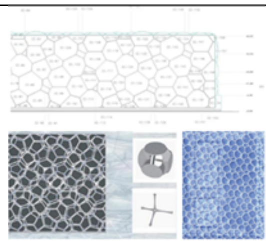
6	(Sinclair Eakin, 2007) (Arup, 2022)[8]				GreenPIX / 2008 / Beijing, China.	Entertainment Complex
7	(Arkitektuel, 2022)[10] (Ruiz-geli, 2022)[11]				Media-TIC / 2010 / Barcelona, Spain.	Information and Communication Technologies Center
8	(Gardiner, 2013)[12] (Kurtperenchio, 2022)[13]				Design Hub / 2012 / Melbourne, Australia.	Exhibition Complex
9	(Aldersey-Williams, 2004)				The Esplanade / 2002 / Esplanade, Singapore.	
10	(Mirkazemi & Mousavi, 2020). (arquidocs, 2008)[15]				The Water Cube / 2008 / Chaoyang, China.	Beijing National Aquatics Center

[8]https://www.arup.com/projects/greenpix-zero-energy-media-wall
[9]http://sgp-a.com/#/single/xicui-entertainment-center-and-media-wall/
[10]https://www.arkitektuel.com/media-tic/
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[12]https://divisare.com/projects/227798-sean-godsell-architects-rory-gardiner-earl-carter-rmit-design-hub
[13]https://www.kurtperenchio.com/case-study-rmit-design-hub
[14]https://structurae.net/en/structures/esplanade-theatres-on-the-bay
[15]https://arquidocs.wordpress.com/2008/08/25/water-cube-en-beijing/

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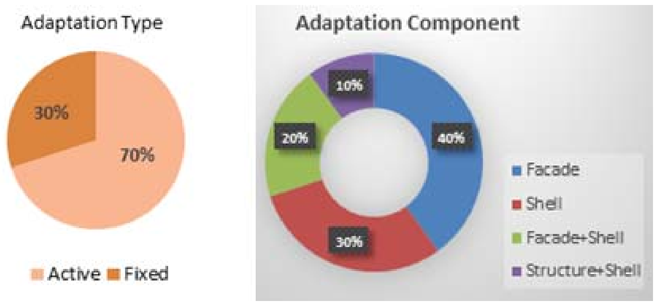
The table containing the information labels of the buildings examined within the scope of the study includes the project names, construction years, locations, building classes, the information of the module used in the building and the schematic representations of the building shells. Building numbers have been given to the examined structures to facilitate further evaluations. Although the examined examples are the most striking examples in the literature, attention was paid to the diversity in the modules while making the selection. For this reason, it was given importance to find examples of patterns designed with geometric, traditional, parametric design and biomimetic approach in the selection of patterns in the modules.

The samples examined within the scope of the study are given in the table (Table 2) below whether they are mobile or fixed as type information. While it is included as component information in terms of its location on the facade, shell, or structure, it has been researched whether it is designed with geometric pattern, traditional pattern, parametric pattern, and biomimetic approach pattern as pattern information.

Table 2. Type, Component and Pattern Information Table of the Projects

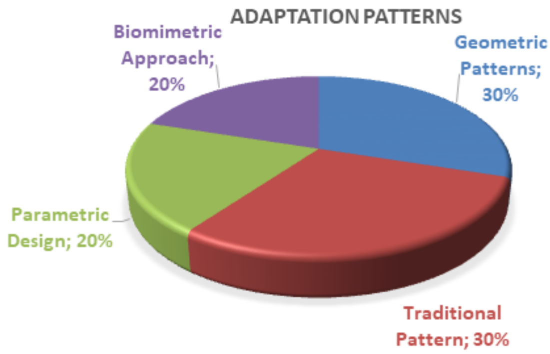
Build No.	Type		Component			Pattern			
	Active	Fixed	Facade	Shell	Structure	Geometric Patterns	Traditional Pattern	Parametric Design	Biomimetic Approach
1	☑	☒	☑	☒	☒	☒	☑	☒	☒
2	☑	☒	☑	☒	☒	☒	☑	☒	☒
3	☑	☒	☒	☑	☑	☑	☒	☒	☒
4	☒	☑	☑	☑	☒	☒	☒	☑	☒
5	☒	☑	☑	☒	☒	☒	☑	☒	☒
6	☑	☒	☑	☒	☒	☒	☒	☑	☒
7	☑	☒	☒	☑	☒	☑	☒	☒	☒
8	☑	☒	☒	☑	☒	☑	☒	☒	☒
9	☑	☒	☒	☑	☒	☒	☒	☒	☑
10	☒	☑	☑	☑	☒	☒	☒	☒	☑

According to the type, composition, and pattern information table of the examined samples, out of 10 samples, 30% used fixed modules in adaptive modules, while 70% used mobile modules. When the adaptation components of the modules of the examined projects are examined, it is seen that 40% of them are used in the facade, 30% in the shell, 20% in the facade + shell, and 10% in the structure + shell. Graphics showing the adaptation type and adaptation rates of the examined projects are given in Graphic 1 below.



Graphic 1. Adaptation Type Numerical Ratios and Numerical Ratios of Adaptation Components

When the adaptation patterns are examined through examples; It was observed that the pattern derived from the 20% biomimetic approach, 30% geometric pattern, 20% parametric design and 30% traditional pattern were used. The Graphic 3 showing the ratios of the adaptation patterns is available below.



Graphic 3. Numerical Ratios of Patterns Used in Adaptation Modules

To see the results of the graphs above, Graphic 4, where the results are combined, is given below.

Graphic 4. Evaluation of Result Ratios

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DISCUSSION

In the selection of adaptation methods, the adaptation parameters of the 10 world-famous example buildings examined within the scope of the study were primarily revealed. Each of the building samples is in a different climate, and no climate-specific selection was made while determining the adaptation methods. The aim is to reveal the adaptive design parameters used regardless of climate in the samples examined and to determine the rate of use of the criteria in the samples with a joint evaluation with these parameters. Examination with parameters suitable for the building and climate conditions will be included in the follow-up studies to be carried out after this study. The parameters included in the adaptation methods are the qualities included in the designs of the samples examined within the scope of the study.

In addition to the adaptation type, component, and pattern research on the selected samples within the scope of the study, an examination was made on the adaptation method used while designing. In the study, as an adaptation method, sensitive to solar movement, sensitive to daylight with lighting, light level control, indoor control with shading, wind compatible and controlled, natural ventilation, thermal insulation, digital media technology, energy production with PV panel, contribution to passive systems, light glare and energy production, climate sensitive adaptive, solar energy gain, optimization in terms of thermal comfort, adaptive to visual comfort conditions, each of the parameters was given an alphabetical method number, and it was determined which parameters were found in the building samples based on the building numbers of the samples examined. The adaptation method table related to the study, 'Table 4', is given below.

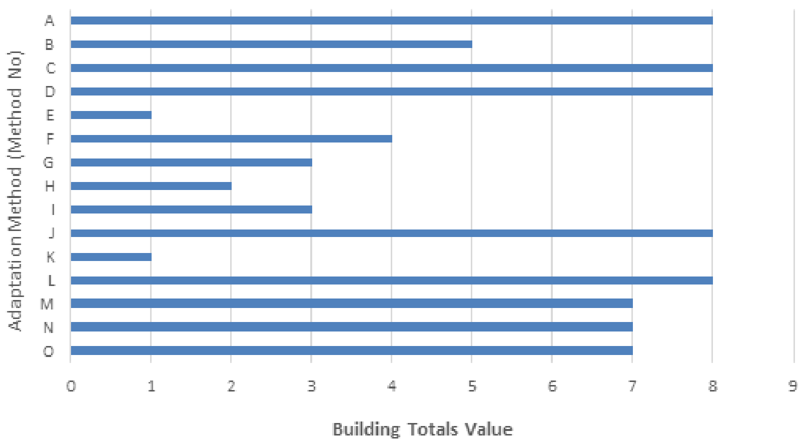
Table 4. Adaptation Method Table

Method No	Adaptation Method	Build Numbers									
		1	2	3	4	5	6	7	8	9	10
A	Sensitive to Solar Movement	√	√	√	√	-	√	√	√	√	-
B	Lighting - Daylight Sensitive	-	√	√	-	-	√	√	-	√	-
C	Light Level Control	√	√	√	-	√	√	√	√	√	-
D	Shading - Indoor Control	√	√	√	-	√	√	√	√	√	-
E	Wind Compatible- Control	-	-	-	-	-	-	√	-	-	-
F	Natural Ventilation	-	-	-	-	-	√	√	√	-	√
G	Thermal Insulation	-	-	-	-	-	√	√	-	-	√
H	Digital Media Technology	-	-	-	-	-	√	-	-	-	√

I	PV Panel- Energy Production	-	-	-	-	-	√	√	√	-	
J	Contribution to Passive Systems	√	√	√	-	√	-	√	√	√	√
K	Flash of Light - Energy Generation	-	-	-	√	-	-	-	-	-	-
L	Climate Sensitive Adaptable	√	-	√	-	√	√	√	√	√	√
M	Solar Energy Gain	-	-	√	√	-	√	√	√	√	√
N	Optimization in Terms of Thermal Comfort	√	√	-	-	√	-	√	√	√	√
O	Adapted to Visual Comfort Conditions	√	√	√	-	√	-	√	-	√	√

Within the scope of the study, the numerical percentage of the adaptation method parameters, whose alphabetic method numbers are given in the adaptation method table, compared to the total number of buildings, has been examined. The numerical Graphic 5, which includes the adaptation methods and the total value of the building, is given below.

According to the above adaptation method and numerical analysis graph of building totals, it was seen that the parameters of A, C, D, J, L adaptation methods were used in 80% of the structures.



Graphic 5. Adaptation Method and Numerical Analysis Graphic of Building Total Value

The parameters of being sensitive to sun movement corresponding to the method numbers A, C, D, J, L, having light level control feature, indoor control with shading, contributing to passive systems, and being adaptable to climate sensitive in the samples are 80% of these features when designing adaptive modules shows that these are the most important parameters to be considered. It has been observed that the parameters of solar energy gain, optimization in terms of thermal comfort and compliance with visual comfort conditions corresponding to the M, N, O method numbers are used in 70% of the samples. It has been observed that energy production parameters are used in 10% of the structures thanks to the adaptability to the wind corresponding to the E, K method numbers, and the control and light shine. It has been observed that the heat insulation and PV panel and energy production adaptation methods corresponding to the G, I method numbers are used in 30% of the buildings. It has been observed that the natural ventilation parameter is used in 40% of the buildings, while the digital media technology parameter is used in 20% of the buildings. When the lighting and daylight sensitivity parameter corresponding to the B method number are compared to the total numerical value of the building, it has been seen that it is used in 50% of the buildings.

CONCLUSION

It is observed that even the designs of the living units where we spend the most time today have undergone great changes over time. The most important reason for this change is environmental factors and its effect on design. It is important to design buildings that can best adapt to environmental factors. When future climate scenarios are examined, it is seen that buildings must be flexible against future global climate changes and unexpected conditions, as well as working with the climate. Today, when changing climatic design parameters are observed, performance-based adaptive designs are becoming increasingly important. Adaptive building envelopes based on performance, which can change according to environmental factors, increase the living comfort in the building, ensure the sustainability of the building, reduce operating costs and are seen as an important solution proposal in extending the life of the building. Reactions based on performance in line with environmental factors allow building envelopes and facades to change and create different morphologies.

In buildings where adaptive building envelope and façade design are used, passive systems are used to a greater extent instead of active systems, and this allows for a reduction in operating costs as well as prolonging the life of the building. With these possibilities, it provides user comfort and provides environmental advantages. In adaptive structures, it enables the building to adapt quickly to the external environment and find practical solutions to user needs, thanks to its ability to be mobile, especially on the facade and the shell. Thus, it helps the building to maintain its life cycle by consuming little or even no energy in some cases. The flexible and dynamic nature of the façade or the building envelope prevents the building from being damaged by environmental factors, but also extends the life of the building thanks to its adaptability to dynamic conditions. Buildings that can adapt to changes in nature and the environment can be more permanent as they can also reduce the effects of environmental changes. In addition, when adaptive buildings are compared with other buildings, it is seen that they reduce energy costs and thus operating costs.

Flexible adaptive façades and building envelopes that allow aesthetic setups can produce different adaptive module variations, resulting in a different architectural composition at different times of the day or in different seasons of the year. Within the scope of the study, the adaptive module variation used in adaptive facades and shells was investigated. The aim of the research is to obtain numerical data by examining adaptation types, adaptation components and adaptation pattern information through the most striking building examples in the literature designed with adaptive facades and building envelopes. In addition, it is one of the main purposes to determine the rate of use of adaptation methods. It is aimed to analyze which parameters are more preferred while designing an adaptive module through the numerical data obtained. Adaptation type, component, pattern, and method parameters were examined by tracing method on 10 structures examined. Comparisons were made by finding percentages on the numerical data obtained. The adaptation type of the module samples of the structures examined in the study, 70% were found to be mobile while 30% were fixed. When the adaptation components of the modules of the projects are examined, it is seen that 40% of them are used in the facade, 30% in the shell, 20% in the facade + shell and 10% in the structure + shell. When the adaptation patterns are examined; It has been observed that 20% biomimetic approach, 30% geometric pattern, 20% parametric design, and 30% traditional pattern are used.

When looking at the examples in general, it has been determined that the modules used in the facade and building shells are mobile. When the adaptation components are examined, it is determined that they are mostly seen on the front, followed by the crust. It has been observed that the biomimetic approach, geometric pattern, parametric design, and traditional pattern are used in almost the same proportions in accordance with the environmental conditions and usage purpose where adaptive module variations vary.

When the adaptation methods are examined, it has been determined that the most important parameters to be considered when designing adaptive modules are the criteria of being sensitive to sun movement, having light level control, shading indoor control, contributing to passive systems and being adaptable to climate sensitive. These features are seen because of the analyses followed by the parameters of solar energy gain, optimization in terms of thermal comfort and adaptability to visual comfort conditions, which are important to use. It was seen that the parameters of illumination and sensitivity to daylight took place in half of the total value of the building according to the numerical values found because of the examination.

It was observed that the natural ventilation parameter was used in 40% of the sample buildings examined within the scope of the study, and immediately afterwards, thermal insulation and PV panel energy production features were used in 30% of the buildings.

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Thanks to the presence of digital media technology in the modules, façade and shell, control, and light glow in harmony with the wind, where the energy production parameters in the samples are the least common features in line with the environmental conditions and the needs expected from the building.

Within the scope of the study, the necessary literature was searched and attention was paid to the selection of building examples that are widely known throughout the world, which are frequently examined in the articles in the literature. As seen on the building labels examined, each sample belongs to a different climatic zone. The results of the study include data on the analysis of the design parameters used on the selected adaptive building examples. While selecting the parameters, a common evaluation was made on the parameters used while designing the buildings within the scope of the samples examined independently of the climatic conditions. Considering the building-specific parameter choices, it is imperative to evaluate the climatic conditions. This study should be supported by future studies. The research supports the collection of preliminary data within the scope of the subject and paving the way for future studies in this field that will be evaluated in the same climate or with different climate parameter inputs.

With the help of developing and changing technology, diversity in building designs that are sensitive to the environment and can adapt to climate conditions has become possible today. It is inevitable that structures that can adapt to climatic conditions and the environment can adapt to all conditions, protect the environment and most importantly be sustainable and be among the first preferred construction techniques of the future. The designs that will be made by considering the environmental data and climate parameters suitable for the project needs will allow the production of new module variations on the facade and the shell and will enable the development of new design methods in architecture. For these reasons, the subject is an area that needs to be investigated in depth and its application methods should be examined. The study aims to shed light on future studies in this field as preliminary information.

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