

Responsive Skin Application Techniques in Energy-Efficient Buildings

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Meryem Alagöz Konur
Department of Architecture
Necmettin Erbakan University
Konya, Türkiye
meryemalagoz@gmail.com

Sevim Gülen Türker
Department of Architecture
Necmettin Erbakan University
Konya, Türkiye
sgozaktan@gmail.com

Pelin Sarıcıoğlu
Department of Architecture
Gazi University
Ankara, Türkiye
pelinsaricioglu@gazi.edu.tr

Abstract—Energy efficient buildings are those that consume less energy with the measures taken during the design process, meet the energy they need from renewable sources, and make a minimum environmental impact by using the energy obtained most effectively. Within the scope of this study, energy-efficient buildings were selected because they emphasize environmental sensitivity in the design, construction, and use phases. The study aims to analyze the sensitive volumes through algorithmic graphic programs and categorize them according to the application technique. The study is based on written sources, internet databases, and photographs. Visuals and examples are used to give details. In energy-efficient building design, responsive skin algorithmic application techniques provide optimum energy in a short time and make a great contribution to the national economy.

Keywords—Digital technology, Energy efficiency, Responsive skin.

I. INTRODUCTION

One of the solutions for the fossil fuel consumption problem, which causes ecological balance to deteriorate and threatens human health to a great extent, is energy-efficient buildings. For this purpose, digital technology is developed to model high-performance structures that offer high comfort with fewer raw materials and to analyze their performance accurately. These digital technologies can be counted as parametric, genetic algorithm, and responsive skin designs that cover these two design methods, depending on the form of application. In the analysis of the designs in the context of energy efficiency, digital programs compatible with digital technologies are used by the target. Therefore, high-performance designs that minimize energy loss and provide energy gain can be made quite easily through digital technology.

In this context, the main feature that distinguishes responsive skin design, which is considered the subject of study, from others; it is adaptable and capable of reversing some of its functions, features, or behavior over time and in response to changing performance requirements and variable boundary conditions [1]. This study aims to analyze responsive skins through algorithmic graphics programs and categorize them according to the application technique.

II. ENERGY EFFICIENT BUILDINGS

Energy-efficient building design can be defined as designing for effective and efficient use of energy by utilizing variable physical environmental conditions such as climate, direction, and wind in the architectural design process. In addition, energy-efficient building design aims to create appropriate active and passive control methods, to increase

building performance and energy efficiency in the fields of heating, cooling, ventilation, and natural lighting [2]. Energy efficient design can be summarized in three complementary steps:

- 1) The first step is to create an architectural plan that aims to save energy, minimize the need for heating in winter and cooling in summer, and increase the efficiency of natural and artificial lighting.
- 2) The second step is the implementation of passive heating, cooling, ventilation, and natural lighting methods best suited to the building type and environmental data, and ensuring that natural energy sources are used primarily.
- 3) The third step is the use of the mechanical system in cases where the indoor comfort conditions are required by function or as a result of the preference of the users, with a high level of comfort expectation, and where natural environmental inputs cannot be utilized. Ensuring the comfort conditions of the building should not be done with mechanical systems alone [3].

III. DIGITAL TECHNOLOGIES IN ENERGY-EFFICIENT BUILDINGS

For energy-efficient design, numerical techniques have been developed to effectively model high-performance structures and to analyze their performance correctly. According to the design method, these techniques can be counted as genetic algorithms, parametric, and responsive designs.

A. Genetic Algorithm Design

An algorithm refers to the variations of the solution of a problem in a limited number of steps by systematic and rational thinking. An algorithm is defined as a sequence of steps necessary for the solution of a problem [4]. The idea of architectural design is similar to algorithmic thinking with this quality. Unlike the traditional design process, the algorithmic design process can produce numerical solutions to design problems with calculations [5].

Fig. 1 is an example of the application of the optimization developed as a result of the analysis with the genetic algorithm. In this example, in the context of energy-efficient building design, the optimal orientation of the facades is desired to maximize the sun exposure of the building. To generate alternatives in terms of sunlight received on the building facades, the surfaces were changed towards sensitive orientations. After this step, the most suitable PV modules for each surface are determined and the PV energy production rate

and the related economic impact are analyzed and compared. [6], [7].

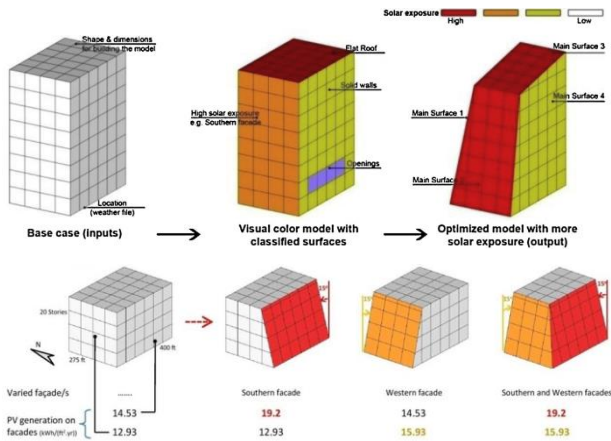


Fig. 1. An example of the application of the optimization developed as a result of the analysis with the genetic algorithm [6], [7].

Computer-aided design tools work and are used thanks to an algorithm setup as in any computer software. However, since this software is designed to be used as a tool, it presents certain objects and functions that are likely to be solutions to design problems. The combination of these objects and functions expected from the designer is to solve the problem. The architect's approach to the design problem from an algorithmic point gives flexibility to the designer while facilitating the traceability of the design process. In complicated architectural design problems, optimization values are changed by increasing the number of parameters, because classical methods remain at limited values. Genetic algorithms are techniques that can find the optimum solution in the shortest time by calculating probabilities [5].

B. Parametric Design

Parametric modeling makes a significant change in the design process. Signs, i.e. parts of the design, are related and change in a coordinated way [8]. The parameter can be expressed as whether a state can be one or more changeable quantities. With this feature, the parametric design differs from the traditional design approach and forms the basis of digital design. In parametric modeling, the design process consists of many phases such as the formation of the design concept, shaping the area where the design will be made, and solving the application details. In the process of creating the design concept parametrically, environmental data or other factors that are decided are interpreted as parameters, and the way of creating a design style is made by using the effect-response method [9]. Since the design process takes place in a changeable system, different alternatives can be easily tried depending on the variables in the design.

The variables to be decided during the building envelope design phase, the built environment data (direction, height of the existing buildings, solar rays, wind, etc.), floor numbers, and heights can be determined as the floor area. Any changes applied to these factors change the design instantly and the result model also changes and updates instantly. The resulting product will be a visual model that can test momentary changes and access the desired technical data.

The skyscraper design in Fig. 2 is an example of parametric design. Since pollination plays a critical role in sustaining human life, honeybees and humans coexist in a

sustainable design that solves the biodiversity problem. The design depends on many parameters such as wind speed, location and height of the building, exposure to sunlight, and bee survival. Considering the sensitivity of bees to wind and nutritional factors for pollination, kinetic façade design was considered appropriate. A parametric model was designed in Revit to design a building based on LEED principles. The facades move parametrically according to the incidence angles of different sun rays. In addition, light-sensitive materials are used to reduce indoor temperature, minimize air conditioning consumption, and prevent glare [10].

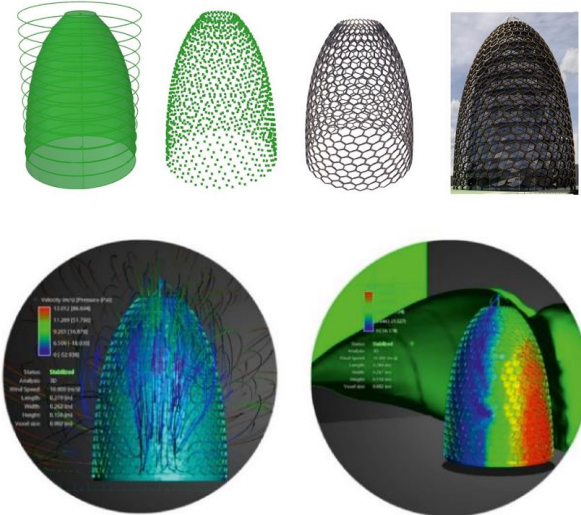


Fig. 2. Structure and Wind pressure analysis of parametric skyscraper designed for biodiversity [10]

C. Responsive Skin

The term responsive is often used interchangeably with “interactive” and “adaptive”, but most simply it is used to describe, “how natural and artificial systems can interact and adapt” [11]. A responsive building skin includes functionalities and performance characteristics similar to those of an “intelligent” building skin including real-time sensing, Kinetic climate-adaptive elements, smart materials, automation, and the ability for user override. But it also includes interactive characteristics, such as computational algorithms that allow the building system to self-adjust and learn over time, as well as the ability for inhabitants to physically manipulate elements of the building envelope to control environmental conditions [12].

IV. RESPONSIVE SKIN APPLICATION TECHNIQUES IN ENERGY-EFFICIENT BUILDINGS

The design of the skin of buildings acquires a strategic role in responding to increasingly complex requirements, opening up to the experimentation of innovative technologies, with the application of responsive systems that make the facades dynamic and allow interaction with different environmental parameters [13]. The responsive skins can be gathered in 3 main groups according to the application type in green buildings.

A. Modular Responsive Skin

It is the design method formed by the adaptation of the modular parts according to the environmental conditions during the shaping of the building. It is the integration of regular forms such as squares, rectangles, triangles of certain sizes, or curvilinear free forms by coming together in a certain

number. These sizes and numbers vary depending on the angle and direction of sunlight or wind.

The skin design of the Hanwha Corp headquarters building in Seoul, South Korea, which was completed in 2020 in collaboration with Arup and Dutch firm UNStudio, is an example of modular responsive skin. On the facades, 239 aluminum modules were arranged in different configurations, and a new system of 54 types of facade modules was used, thus optimizing the amount of sunlight and integrating 301 photovoltaic panels. On the south side of the building, where solar radiation can be the most intense, the modules protrude more to provide extra shading. On the north side, which receives less sun, the modules are slightly recessed to allow more light into the interior spaces of the building [14]. Fig. 3. Shows the optimization model of photovoltaic cell distribution and light exposure analysis [14].

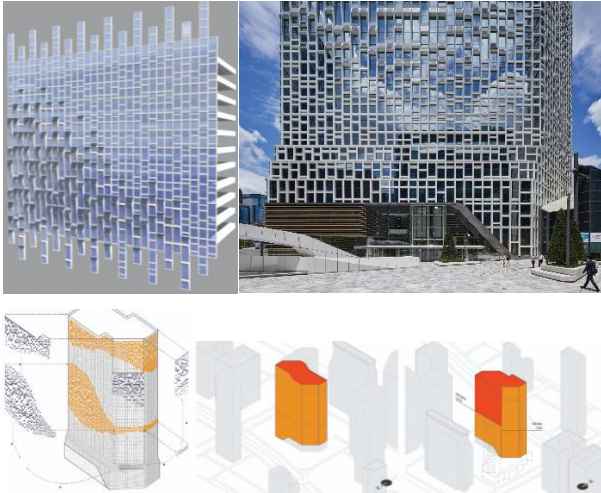


Fig. 3. Optimization model of photovoltaic cell distribution and light exposure analysis [14]

B. Mobile Responsive Skin

It is the design method that is formed by adapting the entire building facade responsibly according to the environmental conditions. The entire facade of the building is in motion, depending on the angle and direction of sunlight or wind.

An example of mobile responsive skins is the parking garage at Brisbane Airport in Australia, designed in 2012 in collaboration with Ned Kahn and design studio UAP. The skin of the building features a dark gray line representing the Brisbane River. From the outside, the eastern side of the parking lot appears to be undulating in the wind.

The 117,000 aluminum panels, which are suspended semi-fixed to the surface and can move mobility, give the skin the feeling of water waves with the effect of the wind. These movable panels reflect light and shadow patterns on the walls and floor as sunlight passes through the facade. The design also provides practical environmental benefits such as shade and natural ventilation (Fig. 4) [15].



Fig. 4. Brisbane Airport Car Park and the aluminum panels used in the facade [15]

C. Screen Responsive Skin

It is a responsive skin application with code software on the building facade. Although the facade itself does not change, it is the perception that the elements on the facade surface are in the same plane as the facade, the waves of obstacles or obstacles, and the perception of the desired part of the whole building or facade.

An example of screen-responsive skin design is a housing project in Los Angeles, USA, designed by Habitat for Humanity and faculty member Darin Johnstone and students from the Southern California Institute of Architecture (SCI-Arc). The design aims to be sustainable, economical, and a design where users will feel safe. The use of smart materials on the skin on a small scale that does not affect the design too much has ensured that the building is not only sustainable but also economical. On the façade facing the entrance courtyard, an 'eco-screen' was used to shade the courtyard, capture energy, and purify the air [16]. The outer layer consists of black metal panels designed to house thin photovoltaic panels on its surface. The inner layer consists of vinyl strips coated with TiO₂ material that traps and neutralizes harmful particles in the air. The skin of the IVRV House provides daylight control by shading with sun-shading elements on the inner and outer layers. Photovoltaic panels placed on the surface of the black metal panel on the outer layer meet the parameters of solar gain control, making it an energy-efficient façade (Fig. 5) [16, 17].



Fig. 5. IVRV House general view of the skin and detailed view of the eco-screen [16,17]

V. CONCLUSIONS AND EVALUATION

Energy-efficient buildings are recognized as ecosystem-sensitive buildings that give importance to climate, environmental conditions, renewable energy sources, and the use of non-waste materials. Today, with the increase in energy awareness, the technological development of energy-efficient buildings is an important agenda item. The role of skin is crucial for optimized energy performance of the building envelope, especially in their application in energy-efficient buildings.

This paper reviews the existing theoretical and analytical review on the applications of responsive skin to create energy-efficient buildings. By examining the examples of modular responsive skin, mobile responsive skin, and screen responsive skin, the study proposes that responsive skin becomes an inherent component for the future development of energy-efficient buildings. In addition to energy efficiency, such designs also provide prestige and rent for the building with the visual feast they provide.

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