The Influence of Using Responsive Façade as a Tool for Improving the Built Environment: Case study: Attaba – Opera square

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Abstract. The path we are currently following to improve the physics of construction due to the destruction of our environment through the negative impact of the built environment around us. Current efforts to decrease carbon and energy are noted by modifying and improving modern "layered" envelopes and improving a misunderstanding of thermal comfort that has become much less effective than expected. Understanding construction physics is an important factor in improving the quality of life indoor and outdoor, relying primarily on theoretical and computational aspects, then applying the practical part to reduce excessive use of carbon and energy and hinder the elaboration of a sustainable and built environment. This paper shows how the problem stems from neglecting to think about the first principles and basic construction physics. Similarly, we show how combining good construction physics with reassessing old methodologies to construction and structure use provides some powerful and effective tools to address the climate emergency. The use of construction physics methods supports the search for new solutions to express the most important factors affecting thermal conduction and minimum surface temperatures. However, buildings have integrated concepts in which advanced systems work together to optimize energy, comfort, and health performance. Convergence between various engineering fields and the overlapping field of construction techniques and services has great potential in the future to achieve the next step in energy saving. As a result, the research highlights new methods that make our buildings interact with the external environment using climate data, responsive envelope design, simulation software, thereby achieving architectural response to surrounding variables, improving building physics to reduce environmental pollution, thermal comfort, and achieving the highest energy efficiency and performance in buildings. This is illustrated by the presentation of a case study of an existing building (Opera Garage Building) – Cairo, it will review solutions to enhance the envelope of the building and its impact on the built environment to come up with some recommendations and solutions which we can apply it on the existing buildings in Egypt.

Keywords: Building Physics- Responsive systems- Building performance- The built environment- Thermal comfort.

1. Introduction

One of the quintessential challenges facing the built environment is its fundamental impact on climate change and the energy sector, as its effects already dominate. Additionally, methods for designing, analyzing, and measuring design solutions of sustainability problems for architects have emerged as pivotal areas of research and development. Building envelope, microclimate, heating, ventilation, and air conditioning (HVAC systems), contribute as main component responsible for energy consumption in buildings. Therefore, sustainable design strategies contain the use of low energy materials for building envelope components, utilizing daylighting to eliminate the need for supplementary artificial lighting during the day, reducing air
conditioning usage through passive ventilation strategies, and proposing shading devices to solar exposed orientations of buildings [1]. Building energy efficiency is often below average, particularly for its envelope and wall/window shading. For hotter regions, improving room ventilation through better positioning of windows, increasing window size, and using adaptive systems would enhance energy efficiency and achieve thermal comfort for users [2]. Nevertheless, modifying the aspects of building physics and using responsive systems will improve the microclimate because it affects the indoor and the outdoor environment quality.

2. Objectives
The paper aims to explain the importance of applying responsive systems as tool for improving the micro climate and the built environment specially the hydroponic system as a vertical farming and green wall. In addition, developing on evaluation method to examine how the thermal insulation and energy efficiency aspects of building physics are incorporated throughout the building delivery process. Study the influence of Responsive systems and potentials of computer applications on architecture to discuss its role and function as a resilient approach. Moreover, the main goal of this paper is achieving the environment indoor comfort in terms of efficient daylight distribution, natural ventilation and thermal comfort- minimum glare and minimum direct sunlight- through responsive skin design configuration on high-rise office building, using simulation and evaluation design tools.

3. Methodology
It includes a comprehensive review of the building legislation in force at the time of planning of case study. The research tries to prove that responsiveness in architecture can decrease the consumption of energy in buildings and it can improve the microclimate in the built environment. Presentation of global models in some countries that have applied new technologies and systems to generate the external envelope to provide the consumption of energy in buildings. The consequences of the research will be achieved via the following research methodology and case study:

4. Problem
The problem of research is that there is a lack of awareness about the significance of using natural resources, which has caused energy consumption at large rates, and this constant and speed raise in energy consumption has led to increasing environmental pollution and CO2 emissions, causing global warming and change in climatic phenomena and temperature changes globally. Therefore, the research spots light on the modern design and construction methods that make our cities interact with the external environment by using modern technology and smart materials, thus realizing the architectural
response to the surrounding changes [3]. In addition, buildings use an excessive amount of energy to achieve thermal comfort and generate electricity so, thus great quantities of energy are being consumed and the rates of energy consumption are increasing rapidly which causes mainly environmental pollution causing increased CO2 footprint then leading to global warming or climate-changing phenomena. Eco-system becomes imbalance and an increase in environmental pollution and overall global international temperature [3].

![Figure (2): Urban Heat Island increases energy consumption and pollution. Source: International Energy Agency](image)

- Buildings are responsible of 45% of the energy consumption in Egypt. (Egypt state of Environment 2006-2007)

Accordingly, the problem is stated as follows; the traditional tools of dealing with complexity which controlling the environmental aspects. As a result, it is essential to consider new technologies and methods in the design process and urban modelling by using responsive systems, computer vision, and simulation applications. This paper shows the challenges in existing building which located in Cairo, this place has many Urbanism and environmental problems such as street vendors, overlapping uses, pollution, and hustle.

5. Questions
This paper clarifies on a lot of questions which in turn can optimize the efficiency of buildings without causing more damage to the environment, like:
- How can the high performance of buildings be achieved through using a responsive systems and modern technology to improve energy efficiency and reach to thermal comfort?
- Is it applicable to apply this technology in Egypt to retrofit the existing building?
- How can the distribution of energy in buildings be controlled by Aerial analysis (Thermal survey) which turns the technology into a powerful, efficient tool?

6. Tools
Simulation programs( Rhino / Envi-met / climate consultant)

![Figure (3): Building Physics simulation analysis via Envi-met. Source: Envi-met website](image)
Aerial Analysis (Thermal Survey), Aerial Intelligence for Retrofit Building Energy Modeling (Air-BEM).

Figure (4): Aerial Analysis thermal Survey, Source: https://www.svvdroneservices.com/thermal-imaging

7. Literature Review

Systematic literature review:

Building facades have a significant impact on energy use for ventilation in buildings that face warm-humid climates in South East Asian countries [4]. The research outlines a three-step process for the design of sustainable facades, as the authors highlight the first step being the analysis of energy consumption, the second step being the reduction of energy consumption by using energy in most efficient ways, and the last step being the fulfilment of remaining energy requirements by renewable energy sources. The research results indicate that following the energy triangle approach has the potential to contribute to sustainable facades in Asia to systematically support building design, which consumes less energy and exploits the potential of natural ventilation [4].

Building envelopes play an important role in global warming and our need to reduce carbon emissions [5]. Their research tried to discover existing visionary building envelope concepts and their relation to maintaining a favourable interior environment. Luther and Altomonte (2007) discuss the concept of biomimicry to combine the most up-to-date building materials and construction technologies for fulfilling the requirements of advanced facades. The authors present building envelopes analogous to nature, physical processes in building envelopes and identify façade as a climate conditioner for increasing thermal comfort. Responsive facades can be designed as vegetation scaffoldings and climate modifiers if integrated with vertical green shading, light shelves, shading devices, and timber screens [5]. The novel contribution of this study included that flexible and environmentally responsible building ‘skins’ should not be designed as separate components protecting the building interior from external factors, but rather utilize them for integrating advanced materials and systems for optimizing the internal environment according to external conditions also possibly trying to generate energy.

The use of double skin facades has increased significantly over the last 10 to 15 years, primarily due to the benefits attributed to them regarding increased energy efficiency and improved daylighting [6]. There is a debate about whether these benefits would be more effective provided by a well-designed, traditional, single-skin façade system. The research discusses the various types of double skin facade systems and explores their features and function.

The Department of Energetics at Politecnico di Torino conducted various experiments on a climate façade with a mechanically ventilated air gap [7]. The measurements were performed using TWINS (Testing Window Innovative Systems) test facility, which consisted of two outdoor cells, one used for
reference purposes, and the other which adopts different active façade configurations. The energy efficiency of the façade and the thermal comfort implications have been evaluated considering the ability to pre-heat the ventilation air in the winter season, and the ability to remove part of the solar load during the summer season; the normalized daily energy passing through the façade and the normalized surface temperature of the inner glass were analyzed [7].

8. Material and Method

Responsive architecture adapts to the surrounding environment causing an alteration in the envelope configuration depends on adaptation. The primary target of a building is to safeguard the inhabitancies from the outer environment and to achieve a comfortable indoor environment. This operation can be reached by the implementation of passive like thermal mass, solar insulation, shading, and natural ventilation. Also, the building was fundamentally designed for the environmental alterations that surround it [8]. Currently, there is a lack of concern regarding the environmental surroundings for the designs of the modern-day buildings; consequently, the building envelope should be designed to be a great potential to save energy and also to react with such alterations. The potentialities of responsive materials and responsive building envelopes contribute to the energy decrease. The responsive architecture enables the architect to design structures that temporary pavilion designed with a stable structure, that can able to adjust to the environmental requests and the changes and needs of the user through the help of suitable technologies [9].

-Responsive architecture: can adapt to corrupting climatic conditions and variables, and that response can be dynamic or static.

Building skins are not considered anymore as an elevation separates inside from outside but as an interactive, responsive element to environment and user’s needs, as shown in figure (5). This paper focused on responsiveness to environment interface [3]. The most important factors causing the increase in carbon dioxide and Caused 80% of this problem is generating electricity and the operating Energy inside the building is affected by:

- Building Envelope
- Material Used
- Climatic factors

Although a considerable amount of architecture projects is planned and executed every year and the knowledge about the planning processes is being applied in the field, the integration of building physics aspects in the building delivery process have not yet been extensively documented.
In contrast, a vast field of studies pertaining to different aspects of building physics can be found. To be able to describe building physics related tasks, it is useful to start by identifying the main building physics aspects in the building delivery process that are relevant for building design, as shown in figure (7) according to design building Wiki (2019) [10]. As a result, understanding building physics is an important factor in improving the quality of life indoor and outdoor, relying primarily on theoretical and computational aspects, then applying the practical part to reduce excessive use of carbon and energy and hinder the development of a sustainable and built environment [7].

**Figure (6): Building Skin Role**  
**Source:** Facades, Knaack, 2007

**Figure (7):** Merging of responsive systems and aspects of building physics. **Source:** by author
The Possibility of applying responsive system in Egypt in Existing buildings: Case Study – Opera square, application of Hydroponic system (vertical farming):

The main objective of this project to develop the area of opera square and between the building of the opera garage and Al Attaba and the re-use of the two buildings will positively return to the economic revitalization of the area because it will provide organized places for the street vendors, in addition to that, will revive garages and make them organized commercial spaces in the center of the capital, Cairo. The region lacks entertainment and picnic places for the citizens, which we seek to get rid of by providing recreational places for the people of the region (Environmental aspects). Despite the privileged location of the opera square, as it is located in the heart of Cairo near many commercial centers and markets, in addition to the fact that it faces many challenges that represent obstacles in the way of developing the field and the most important of these challenges:

1- Overlapping Land-use
2- Street vendors
3- Pollution and noise

This project aims to create a lung that will serve users and inhabitants in this place to create an urban area where it can be moved and engage to social activities without affecting traffic in the area, the opera square area is characterized by a very crowded and densely populated area and does not have any green areas or gathering points that distinguish that urban area, as there is an opera garage, which is a concrete building consisting of 5 floors but is not used well due to the heavy overcrowding and polluting area.
Tools:
- Envi-met Software
- World Weather Data
- Climate consultant for climatic data

This steps illustrate the site analysis data and simulation for the existing situation by using Envi-Met Software to know thermal comfort indoor and outdoor and the effect of building envelop to reach to the outdoor and the indoor environment quality.

**Figure (10):** Temperature analysis, Source: by Author, using Envi-met software

**Figure (11):** Wind analysis, Source: by Author, using Envi-met software
This table explain the maximum and minimum degrees and ratios for temperature, wind, and predicted mean vote to be able to reach to thermal comfort. Results show that this area need trees and green spaces to reduce the effect of CO2 emission and the high temperature. Convergence between various engineering fields and the overlapping field of construction techniques and services has great potential in the future to achieve the next step in energy saving. As a result, the research highlights new methods that make our buildings interact with the external environment using climate data, responsive envelope design, simulation software, thereby achieving architectural response to surrounding variables, improving building physics to reduce environmental pollution, thermal comfort, and achieving the highest energy efficiency and performance in buildings. This is illustrated by the presentation of a case study of an existing building (Opera Garage Building) – Cairo, it will review solutions to enhance the envelope of the building and its impact on the built environment to come up with some recommendations and solutions which we can apply it on the existing buildings in Egypt.
The main findings of this study are:
- The responsive façade reduces energy consumption and carbon dioxide emissions, depending on the climatic condition of the building.
- The allowance of entering the natural light inside the building depends on the material of responsive units and climatic analysis.

Figure (13): Proposal for the main façade applying vertical farming, Source: by Author

Conclusion:

The world is facing a quintessential problem characterized in the lack of energy and pollution related to the ever increase in energy consumption. The buildings contribute to these problems as they are allowed the main consumers of energy and contribute to increasing environmental contaminate. Designing buildings to achieve thermal convenience is associated with studying the mechanisms of heat transfer between the building and the outdoor environment. The main findings of this study are:
- The responsive façade reduces energy consumption and carbon dioxide emissions, depending on the climatic condition of the building.
- The responsive systems have a positive effect for improving the microclimate, and it’s important to understand the building physics elements to decrease the negative effect of the built environment.
- In general, windows are considered the weak point in the cover of the building in terms of thermal insulation, but with the rapid progress of technology recently, especially in the field of materials engineering and nanotechnology, there is glass with advanced features and highly advanced performance such as glass with vacuum insulation equivalent to isolation insulation of a wall consisting of several layers, and glass It can generate solar power while it is transparent, intelligent glass can be controlled by its transparency and wireless heat acquisition automatically or through a smartphone, and many other technologies [11]

**Recommendation and Future Studies**

The following are recommendations for the architects and government in order to enhance the application of responsive systems in Egypt specially in existing buildings which consume a large amount of Energy:
- The direction of responsive facade, whether it is vertical or horizontal.
- The mechanism of movement which should not be a complicated movement in order to avoid the system’s failure.
- The importance of study site analysis and climatic condition of the area and building to know which a suitable system to use
- Study ways of integrating the building, and maximizing energy efficiency and improving the building's thermal performance.
- Knowledge into a design strategy that assist designer into the design process in making performance based into integrated application in climate-responsive building elements.
- The role of responsive systems as a means of solving the energy consumption problem in buildings.
- The role of computational design to change all design processes and environmental analysis and solve the problems of energy consumption in buildings.
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