International Journal of Multidisciplinary Research and Growth Evaluation.

Evaluation of sustainable climate-responsive façade in mixed-use high-rise development in Lagos, Nigeria: A study of Eko Atlantic City

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Article Info

ISSN (online): 2582-7138
Volume: 05
Issue: 04
July-August 2024
Received: 07-05-2024;
Accepted: 11-06-2024
Page No: 336-341

Abstract
Climatic-responsive architecture is characterized by its effective integration of local climate elements to achieve occupant thermal and visual comfort with minimal or no reliance on non-renewable energy sources. The study adopted architectural qualitative techniques to identify various climate-responsive façade in mixed-used high-rise developments in Lagos, Nigeria. Four forms of Double-Skin Façades, building integrated photovoltaics (BIPV), vertical greenery systems, and Advanced Shading Systems (Passive and Active) as essential strategies that should be incorporated into mixed-use-high-rise buildings. As a result, while lowering the building's need for artificial energy, the responsive façade produces a cozy interior. This means that when designing a building that adapts to the climate, the local climate in the area where the mixed-use high-rise structure is being taken into consideration. The study concluded that, given the growing popularity of mixed-rise construction in Lagos, Nigeria, the identified climate-responsive building techniques ought to be adopted.

Keywords: climate, responsive, building façade, mixed -use, high-rise, Nigeria

1. Introduction

Globally, the earth's temperature has risen abnormally due to global warming (Ahmed *et al*., 2019) [2]. Global warming is primarily caused by the effect of rising carbon dioxide and other greenhouse gas emissions, which trap heat continuously. One of the main contributors to GHG emissions, which are seen as the primary cause of climate change, is the use of non-renewable energy sources in buildings and industry (Silvero *et al*., 2019). Climate-responsive design is one of the fundamental prerequisites for directing the building industry toward sustainable development (Szokolay, 2012; Yassaghi & Hoque, 2019) [25]. A high-rise building has recently been viewed as a structure whose height is beyond the reach of available firefighting equipment, its number of stories necessitates that residents use an elevator to get to their destination, and its height can seriously affect evacuation (Shen & Sun, 2020). Furthermore lateral and vertical real estate mixed-use has emerged as a key component of sustainable urban land use in recent years. International scholars and practice have consistently demonstrated the positive social and economic effects of mixed-use developments (Shen & Sun, 2020; Madsen & Paash, 2023) [15].

Despite the upspring of high-rise buildings in prominent states in the country, studies on the climate-responsive façade in such a building in Nigeria are still scanty. For instance. Bello, Hamza & Abdulhamid (2021) carried out a study on exploring Double Skin Façade as a Strategy for Achieving Thermal Comfort in a Proposed Mixed-Use Office Complex in Kano, Nigeria. In another study, Reza and Suleiman (2021) Assessed the effect of prefabricated double-skin Façade on the Thermal Comfort of Office Building to achieve Sustainability. Furthermore, Idris and Dawi, (2019) looked at the potential of integrated smart façade for office buildings in Abuja, Nigeria. In addition, Alkali, et.al. (2020) [4] assessed architects' use of principles of climate-responsive architecture for residential design in Northeast, Nigeria. Analyzing the aforementioned studies, it can be suggested that there are context gaps that need to be filled. The current study seeks to identify various architectural climate-responsive facade strategies suitable for mixed-use high-rise buildings.

Can we incorporate the Aim and objectives of this study in the introduction? Also, let's put a conclusion note in the introduction.

Literature Review

Mixed-Use High-Rise Buildings

A building is a closed entity with a roof, walls, floors, and typically windows. The structure can take on various shapes, one of which is a high structure. In a high building, most of the stories are connected by elevators or lifts that allow residents to travel to different levels of the building vertically. The most notable tall structures are referred to as "tower blocks" in Britain and certain other European countries, and "high-rise buildings" in the majority of other countries.

A structure is considered high if its height exceeds the width of two streets, whether it is situated at an intersection, or the adjacent street right of way (Milton, 2018). From another perspective, a building with more than five stories (including the ground floor) and/or a height above 12 meters is considered a high-rise according to the Lagos State Urban and Regional Planning Development Law (2005). In tandem with the aforementioned, from structural engineering theory, a building is considered high once lateral forces have a noticeable impact on the stability and behaviour of the structure (Islam & Islam, 2014). Furthermore, a high-rise building is often defined as one that has 12 stories or more, is utilized for both commercial and residential uses, and is particularly useful in a mixed-use development. This definition is based on the diverse ideas and viewpoints regarding high-rise structures. Adopting mixed-use development results in a more dynamic urban area, increased security and safety, more social connections, and a decrease in daily travel (between home and work), which in turn reduces traffic and prevents the city from developing horizontally (Asgharzadeh & Yazdie, 2011).

Climate Change

Climate change, according to Madu (2016), is a statistical variation that lasts for a long time, usually decades or more. The slow, steady rise in the average surface temperature of the planet is one of its features, as is a change in the frequency and intensity of occasional weather events. According to the definition, every country has a variety of weather patterns that are susceptible to variations in the climate. Climate change is the term used to describe variations in the mean or variability of the climate's qualities that last for long periods, usually decades or more (Olaniyi, Ojekunle & Amujo, 2013). Variations in the quantity of energy stored by the "climate system" lead to climate change. The variation happens when there is an imbalance, say between the energy that is radiated and the energy that is received from the sun. Numerous natural processes, including shifts in the earth's composition, fluctuations in ocean circulation, and variations in the earth's orbit, might contribute to this disruption. Therefore, the long-term shift in climate variability is referred to as climate change, according to the Inter-governmental Panel on Climate Change (IPCC, 2018). In addition to external factors like fluctuations in sunshine intensity and human activity, these changes are the consequence of dynamic processes occurring on Earth.

Climate responsive façade architecture

Climatic-responsive architecture is characterized by its effective integration of local climate elements to achieve occupant thermal and visual comfort with minimal or no reliance on non-renewable energy sources (Alkali, Jie, Dahbi & Danja, 2020) [4]. Climate-responsive design is one of the key prerequisites for directing the building industry toward sustainable development. Design methodologies that are climate-responsive take into account meteorological factors.

Optimizing climate factors such as air temperature, relative humidity, wind, irradiation, and rainfall can significantly lower the energy required for heating and cooling buildings. However, evaluating the impact of climate change and improving the environmental performance of buildings is the cornerstone of climate-responsive design (Lamsal, et.al., 2021) [13]. Stated differently, attempting to mitigate resource consumption and adverse environmental effects by working with the external environment. Thus, climate-responsive architecture can greatly reduce building energy use without compromising modern living standards (Reza & Suleima, 2021).

Integration strategies for façade systems of high-rise buildings

Façade systems are widely acknowledged as practical and efficient ways to reduce carbon emissions through energy generation and/or conservation. Double-skin façades (DSFs), building integrated photovoltaics (BIPV), building greenery, and improved shading systems are a few advanced façade technologies that are especially good at cutting energy usage.

Double-Skin Façades

Double-skin façades (DSFs) are one of the most promising sustainable façade technologies. A building system known as a double-skin façade is made up of an intermediate cavity, an outer skin, and an inner skin that are usually made up of glass assemblies (Reza & Suleiman, 2021). Glass skins with single or double glazing units at 20 cm to 2m intervals are available. Usually, controlled ventilation and solar protection are employed in the intermediate space.

The DSF has attracted the interest of architects and engineers in both new and retrofit construction projects seeking to attain zero energy and zero carbon structures, as a result of the development of sustainable building norms. Double-skin façades perform less well in the summer, as Zhou and Chen (2019) [28] contended. Consequences include strong solar radiation, high ambient temperatures, and the need for a continuous, low wind speed, all of which reduce the effectiveness of natural ventilation in subtropical regions.

Building Integrated Photovoltaics

Building integrated photovoltaics (BIPV) offers a technically viable, cost-effective, and aesthetically pleasing way to include solar cells that harness solar radiation to produce electricity into building envelopes intended to support a built environment that is carbon neutral [60]. Because of this, BIPV is now widely recognized as a useful strategy for reaching global goals for reducing greenhouse gas (GHG) emissions (Shirazi, Zomorodian, & Tahsildoost, 2019) [23]. PVs can be installed on the roofs and facades of both new and existing buildings. A large expansion of PV areas is necessary for the decarbonization of the electricity system, and this expansion must frequently be achieved with minimal additional land use.

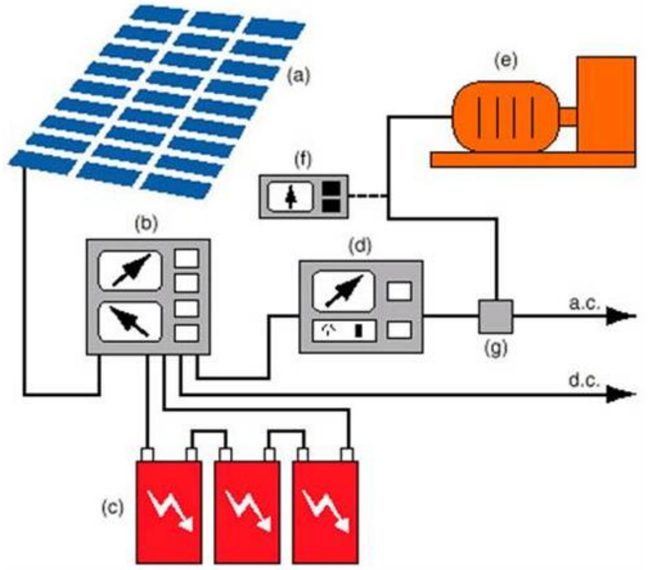

Fig 1: Building integrated photovoltaics (BIPV)

Fig 2: Vertical Greenery Systems

High-rise buildings usually have relatively limited roof area because installing HVAC (heating, ventilation, and air conditioning) systems sometimes need the roof, making façade areas more important. As a result, Mixed high-rise development in Lagos state necessitates giving PV application to buildings a façade-focused consideration.

In contrast, BIPV systems replace the climatic screen, which doubles as a power source for energy generation in addition to acting as an outer building envelope covering. Thus, BIPV can result in material and labour savings in addition to a reduction in electricity expenditures (Peng, Huang, & Wu, 2011) [17]. Additionally, BIPV systems can be connected with other important technologies, such as shade systems. When paired with the implementation of suitable shade configurations, BIPV systems have the potential to cut yearly building energy usage by up to 42%, according to an analysis of instances conducted in various climates (Settino, Carpino, Perrella & Arcuri, 2020) [19]. They underlined that good BIPV design is essential to meeting the NZEB targets and increasing the share of renewable energy in high-rise structures.

Vertical greenery systems

As a sustainable way to keep the building envelope from absorbing too much solar radiation, green systems including green roofs and vertical vegetation systems have been used (Figure 2.5). Aside from that, vegetation systems have numerous benefits for the urban environment. They can reduce urban heat islands, lower ambient air temperatures by absorbing incident solar radiation, and generally enhance the aesthetic value of buildings (Seyam, 2019) [20]. The vegetation systems lower the building's thermal load and, thus, its power consumption by lowering the surface temperatures of the walls and roofs. In this research, we explicitly address whether vertical green systems (VGSs) are a suitable technology for enhancing façade performance, as our goal is to highlight the potential of façade system technologies development.

Numerous vertical green system types have been developed and explored, such as cable and wire-rope net systems, vegetated mat walls, modular living walls, green facades, and numerous combinations of these types (Radic, Dodig, & Auer, 2019) [18]. Green facades are characterized as facades covered in vegetation that serve as shade structures and sound-absorbing materials to reduce temperatures and protect residents from outside noise. Regarding how they incorporate plants onto building surfaces, vertical greenery systems can be distinguished from one another. For example, vegetated mat walls and modular living walls are usually attached to the building's structural framework and can accommodate a wider range of plant species. Because they weigh less and require less maintenance, cable and wire-rope net systems are more effective.

Additionally, because they are not attached to building walls, they may be less vulnerable to harm from climbing plants. Larger tree species can be planted in balcony gardens, which can be integrated with living wall systems. However, these balconies usually need to be integrated into the main load-bearing structure of the building due to the increased weight imposed by larger plants and soil mass. Significant seasonal variations that can be used for aesthetic purposes are another advantage of having a wider diversity of plants in these vertical greening systems.

Advanced shading system (Passive and Active)

In sub-tropical regions, where there is a strong need for cooling and a reduction in unwelcome direct sunlight, shading solutions are essential to sustainable architecture practices. Depending on how they are designed, advanced shading systems fall into two categories: passive and active. In addition to internal shading, passive shading systems such as overhangs, external roller shades, and Venetian blinds are used worldwide as standard passive techniques to shield buildings from intense solar radiation while potentially lowering energy usage (Freewan, 2014) [10].

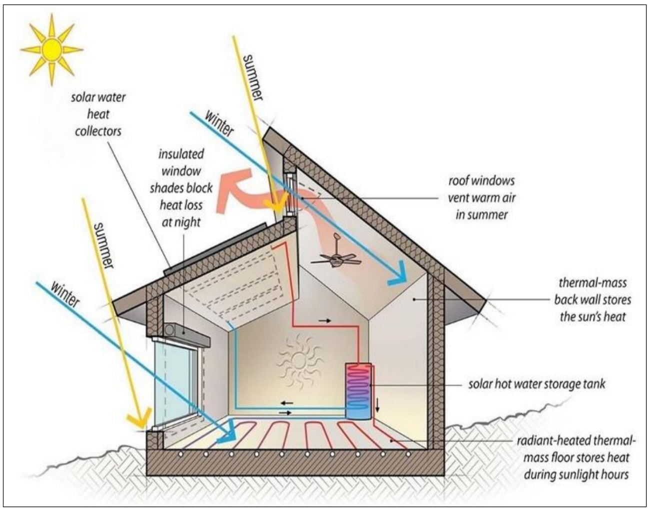

Fig 3: Passive Design

Vertical side fins and horizontal overhangs are frequently used as passive shading mechanisms. A growing number of building facades are being equipped with active shading systems that can adapt to shifting interior and external conditions. Smart glazing, kinetic shading, and integrated renewable energy shading are the three sub-groups into which they fall. In warm, humid areas, smart glazing like electrochromic windows (EC) can reduce air conditioning energy use by up to 50% (Al-Masrani .& Al-Obaidi, 2019) [5]. With the help of parametric design, kinetic shadings, which are innovative façade devices made up of movable components that are controlled algorithmically, have shown the ability to maximize dynamic internal daylight and improve the visual comfort of the inhabitants.

Empirical Review

In a simulation study, Haase and Amato (2016) [6] calculated the cooling energy savings for various DSF systems. Their findings showed significant cooling savings of up to 17 per cent, even during the three hottest months, indicating a 25 per cent reduction in peak cooling load in comparison to a traditional curtain wall system. Idris and Dawi (2019) looked at the potential of integrated smart façade for office buildings in Abuja Nigeria, from a green retrofitting perspective, through integrated smart Façade green retrofitting in existing buildings' façade. A Critical literature review and the study established that façade integration of building service in standard has been stated to have blessings not simplest in phrases of performance, but additionally from a constructional factor of view.

Alkali *et al*. (2020) [4] in their study evaluated how architects in Northeast Nigeria apply the concepts of Climate Responsive Architecture (CRA) to residential design to rate the barriers to CRA implementation. Using field surveys of practising architects in the area, it was determined that, aside from the use of vegetation, architects seldom apply many passive design principles because of the following ranking factors: socio-cultural needs, client preference, poor perception of local/traditional building materials, lack of knowledge about the principles of climate responsive architecture, and perceptions of high costs associated with implementing climate responsive architecture. To improve thermal comfort and lessen the building sector's carbon footprint, the study recommends establishing the importance of climate-responsive architecture in student curricula and raising awareness of the need for it in the public realm. In another study, Reza and Suleiman (2021) focused on double-skin façade (DSF) as a means to enhance the indoor thermal comfort of office buildings in Abuja Nigeria. The result showed that DSF has the potential to improve the indoor thermal comfort of office buildings and reduce energy usage. Additionally, Bello, Hamza, and Abdulhamed (2021) tested the air gap between the double skins in their study to investigate double skin façade as a strategy for enhancing indoor thermal comfort.

The impact of the double-skin façade on increasing internal thermal comfort in the office complex was simulated and evaluated using data from the climate and weather. Their final base case model, which depicts the hours of comfort and discomfort for the simulated office building, demonstrates that a double skin façade can boost indoor thermal comfort in a building and that the bigger the air gap, the higher the thermal comfort.

In a distinct study, Dhamai and Bajiracharya (2022) looked at and qualitatively studied Dhading's architectural components in addition to its instances of modern and traditional residential buildings. The climatic statistics for Dhading show that most of the year is hot. The bioclimatic chart illustrates that midsummer temperatures are high during the day, hence passive cooling strategies are recommended. The Mahoney table recommends having continual ventilation on top of thick walls. According to the study, historic buildings had lower interior air temperatures but greater interior humidity levels. However, compared to modern buildings, Dhading's traditional architectural features and materials are more climate-responsive.

Ahriz *et al*. (2022) [3] assessed the application of DSFs, and their effectiveness in enhancing the energy performance of tall office buildings in the Mediterranean's hot, dry summers, and to create the best DSF model possible for this climate based on industry standards and suggestions for high-performance DSF parameters. Two different factors were considered to assess the effectiveness of DSFs: the number of DSFs employed and the building orientation. This study employed an experimental (produce and test) research approach, and 15 single façades, juxtaposed façades, three façades, and four façades on cardinal orientations were evaluated using computer simulations created with analysis software. Next, a comparison was made between the energy usage and savings that were documented and the reference model. The findings showed that one of the three DSF models, the S14 model, decreased energy use by 28% when heating and 53.5 per cent when cooling a high-rise office building in the Mediterranean's hot, dry summers.

Also, Don *et al*. (2023) investigated the efficiency of the technologies and façade systems currently employed in sustainable building designs. The double skin façade system was found to be the most promising technological solution for improving energy efficiency and developing sustainable building designs based on the investigation. Moreover, adaptive façade systems enhance building performance and occupant comfort via active principles. However, the lack of design rules and challenging design and construction difficulties impede the development of adaptive façade systems. The assessment states that designers, engineers, and builders must consider the sustainable façade system, which offers lower costs, more occupant comfort, and less environmental effect when creating a sustainable building design.

Methodology

This study adopted a qualitative research design to achieve the study objective. Qualitative research. According to Creswell (2013), qualitative research is based on assumptions and uses theoretical and interpretative frameworks to be able to approach studying specific problems or situations. The possible approaches, from the qualitative position (narrative research, phenomenology, grounded theory, ethnography and case study) provide a particular perspective throughout the research process, which begins with the approach itself, through the collection of data, the analysis process, until reaching the final report of identifying the various architectural. In the current study, the current study reviewed the relevant journals on climate-responsive facade strategies suitable for mixed-use high-rise buildings.

Results and Discussion

The study aimed to identify various architectural climate-responsive facade strategies suitable for mixed-use high-rise buildings. Using a qualitative architectural research design, with emphasis on the review of journals and articles on the concepts of the study. The study presented the concepts review of the study variables, which are; mixed-use high-rise buildings, climate change and climate responsive façade architecture. From the conceptual review, a shred of evidence indicated that a mixed-high-rise building requires a climate-responsive façade to dissipate the heat and enhance thermal comfort in hot dry climates.

From the review, four forms of climate responsive façade were identified. The facades are; Double-Skin Façades, Building Integrated Photovoltaics (BIPV), vertical greenery systems, and Advanced Shading Systems (Passive and Active). The aforementioned facades are essential and they should be incorporated into mixed-high-rise buildings to create a comfortable interior while reducing the building's reliance on artificial energy. With that, the design of a building that adapts to the climate takes into account the local weather in the location where the structure is being built. Drawing from the findings, it can be concluded that since mixed-rise buildings have been in vogue recently in Nigeria, the available climate-responsive strategies should be adopted.

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