كلية الهندسة بشبرا
FACULTY OF ENGINEERING AT SHOUBRA
ERJ
PRINT ISSN 3009-6049
ONLINE ISSN 3009-6022

ENGINEERING RESEARCH JOURNAL (ERJ)
Volume (54),Issue (1)
January 2025, pp:103-110
https://erjsh.journals.ekb.eg

Significance of implementing Climate Responsive Streetscape in Cairo Neighborhoods

Nada Mohamed Mostafa Mansi [1,*], Samah Elkhateeb [1], Marwa Khalifa [1]

[1]*Department of Urban Design and Planning, Faculty of Engineering, Ain Shams University, Cairo, Egypt.*
**Corresponding author*

E-mail address: nadamansi31@gmail.com, samahelsayed@gmail.com, marwa1973@yahoo.com

Abstract: The advancement of earthquake early warning systems (EEWS) plays a pivotal role in reducing the detrimental impacts of seismic events on human lives and infrastructure. This paper introduces a novel method for synthesizing seismic digital waveforms tailored specifically for EEWS applications. The method leverages Green's functions, which effectively characterize the Earth's response to a point source. By utilizing these functions, we simulated the propagation of seismic waves originating from diverse earthquake sources and tracked their movement to a designated receiver location. To evaluate the effectiveness of this approach, we conducted a thorough validation by comparing the synthetic seismic waveforms produced by the proposed method with real seismic waveforms recorded from historical earthquakes. The results demonstrate that the synthetic waveforms align closely with the real data in terms of amplitude, frequency content, and arrival times. This accuracy underscores the potential of the proposed method to significantly enhance the precision of seismic waveform simulation, thereby strengthening the foundation of EEWS.

Keywords: Earthquake Early Warning system, Synthetic seismic waveforms, Green's functions.

1. Introduction

1.1 Background

Cairo, a dense urban area with diverse urban forms, is experiencing the effects of rising temperatures and the urban heat island (UHI) effect, exacerbated by ongoing urban development over the past 50 years. This climate change impact results in higher air pollution, temperature variations, and reduced nighttime cooling, contributing to discomfort, respiratory issues, and decreased physical activity, as residents avoid walking or cycling. To address this, the study focuses on enhancing outdoor thermal comfort by creating thermally comfortable, pedestrian-friendly streets through climate-responsive streetscape designs with the help of the following questions.

1. How does the UHI effect impact outdoor thermal comfort in Cairo's neighborhoods?
2. 2. What role do streetscape design elements (e.g., shading, vegetation, materials) play in mitigating heat in public spaces?
3. What are the challenges and opportunities in implementing climate-responsive streetscapes in Cairo's hot, arid climate?
4. How can these streetscapes improve public health and outdoor thermal comfort in Cairo?

Research Aim and Objectives

The study aims to explore the impact of climate-responsive streetscape designs on outdoor thermal comfort, environmental sustainability, and urban resilience. It seeks to assess how these designs can mitigate the UHI effect, improve public health, and contribute to sustainable urban development. The research will analyze case studies from hot, arid climates, identify effective interventions, and propose strategies for integrating these designs into Cairo's urban planning policies. The goal is to create guidelines for designing climate-responsive streetscapes to improve both accessibility and environmental quality.

1.2 Literature Review

The urban heat island (UHI) effect in Cairo is amplified by rapid urbanization driven by population growth, migration, and development. The shift from natural landscapes to impervious surfaces like asphalt and concrete exacerbates heat retention, elevating urban temperatures. These surfaces absorb solar energy during the day and release it at night, creating thermal disparities between urban and rural areas. The lack of vegetation reduces evaporative cooling, further contributing to the heat stress in urban centers. This transformation intensifies the UHI effect, impacting both the city's climate and residents' well-being. [1]

Studies have shown that Cairo's urban areas experience significantly higher temperatures than surrounding rural areas, especially during heatwaves. Research by Abdel-Ghany [2] highlights that the intensity of the urban heat island [UHI] effect increases energy consumption, as higher urban temperatures lead to a greater demand for cooling systems. This increased energy usage, in turn, worsens the UHI effect, creating a cycle that further elevates temperatures and energy demand in Cairo's urban environment.

Research by El-Askary [3] examined temperature trends in Cairo over the past few decades, revealing a significant rise in temperatures linked to global climate change. The study analysed the Surface Urban Heat Island [SUHI] in Greater Cairo over 17 years, using MODIS data to track spatial and temporal variations. Findings showed that SUHI intensity has decreased due to albedo changes and land surface temperatures [LSTs]. Additionally, the extent and intensity of SUHI are influenced by land cover types and climate variability, affecting Cairo's urban heat dynamics.

High population density, extensive pavement, and minimal green space intensify this effect. Construction materials like concrete and asphalt worsen thermal conditions, leading to higher temperatures and reduced comfort, particularly in summer. Conversely, areas with vegetation, such as parks and tree-lined streets, help alleviate the UHI effect by providing shade and enabling evaporative cooling [4,5].

Public spaces in Cairo's urban neighbourhoods, especially streets, play a vital role in social interaction, cultural expression, and commerce. Streets in historic areas like Islamic Cairo serve as bustling hubs for daily activities such as street vending and communal gatherings [5]. Economic activity thrives in these spaces, with markets and street vendors prominent in both historic and modern districts. However, rapid urbanization has introduced challenges like congestion and pollution. Sustainable urban planning initiatives, including the integration of green spaces and pedestrian-friendly designs, are essential to improving Cairo's street quality and liveability. [6]

Thermal comfort is a complex concept influenced by multiple factors including air temperature, humidity, wind speed, solar radiation, clothing, and activity levels [Jones, 2001]. It is subjective, requiring individual evaluation. Various thermal indices, such as the Predicted Mean Vote [PMV] and Predicted Percentage Dissatisfied [PPD], measure outdoor comfort by integrating environmental and personal variables [7]. These indices help understand human thermal comfort, though subjective factors like psychological responses also play a key role. Empirical data from field surveys offer additional insights into thermal comfort in public spaces.

The Outdoor Thermal Comfort Index [OTCI] is tailored for outdoor environments, combining meteorological data with human thermal physiology. It considers urban morphology, like street canyons' geometry, trees, and building height, which influence airflow, shading, and thermal comfort. Studies reveal that dense, chaotic urban structures hinder ventilation, while building heights affect the Urban Heat Island [UHI] effect. Research also shows thermal comfort is influenced by parameters like air temperature and humidity, with user perceptions of comfort strongly tied to these conditions in various climates.

Urban thermal comfort in hot arid regions, like Cairo, depends significantly on radiant heat exposure. Shading is essential to mitigate outdoor discomfort, particularly in summer [8]. Historically, urban designs focused on sheltering indoors from the climate, often overlooking the outdoor climate's impact [9]. Recently, urban climatology has integrated multiple disciplines to enhance outdoor environments [10]. By regulating urban geometry, vegetation, and building materials, urban design can influence microclimates. Effective climate-responsive design requires balancing between day/night or seasonal trade-offs, emphasizing local research to optimize thermal comfort.

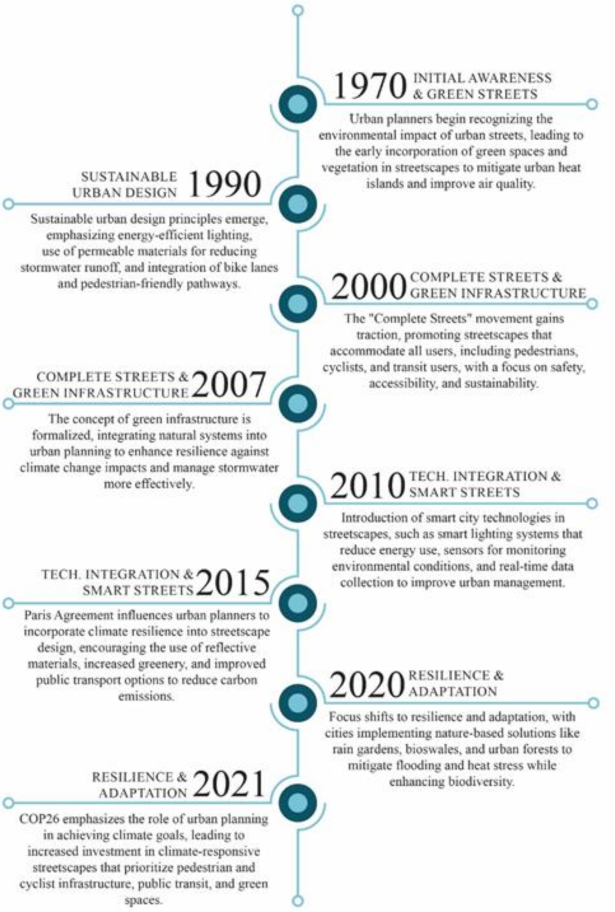

FIGURE 1. Timeline showing the emergence of climate adaptive design approach

Climate responsive urban design was holistic concept that was tackled since the emergence of the negative effects of global warming on livable urban spaces as shown in figure 1 and it developed as a discipline focused on mediating site, climate, and people by combining spatial elements in a way that provides protection from negative and exposure to positive aspects of climate [10]. Climate responsive design keeps the full picture of microclimatic effects over summer and winter in mind. However, it often focusses on countering urban heat buildup during summer periods. The reason is the many impacts of heat on urban areas, from health and mortality to infrastructure. [11] The decision to go to and stay at an outdoor urban space largely depends on the "level of satisfaction or dissatisfaction under the prevailing climatic conditions" [12]

Urban design is key to enhancing public space quality by implementing mitigation strategies like green roofs and parks to reduce air temperatures city-wide, and adaptation techniques like urban canopies for localized cooling. Thermal retrofitting covers thermal comfort, urban cooling technologies, and public space use. Climate-responsive design aims to control solar radiation, wind exposure, temperature, and humidity [13]. It promotes evaporative cooling through plants and water and encourages heat loss from surfaces. These interventions increase the usability of outdoor spaces year-round.

The concept of "urban cool spots" was discussed by [14] [or "cool urban retreats" and "cool urban oases"] refers to public spaces that reduce perceived temperatures, making them comfortable gathering spots during hot periods. These spaces, ranging from squares to street furniture, integrate climate-responsive design and social activities. They use both temporary and permanent strategies, such as misting canopies and water features, to modify microclimatic factors like temperature and humidity at a human scale, naturally becoming social hubs due to their thermal comfort.

1.3 Identification of Climate responsive streetscape interventions

By thoroughly analyzing a number of case studies that discussed mitigation strategies of the climatic effects of UHI in hot arid climate, it was found that all studies emphasize the importance of climate-adaptive design and the use of cool materials and vegetation to mitigate urban heat and improve thermal comfort. The distinct approaches each research used were as follow; Lotafa [15] focuses on informal urban areas with a holistic design framework, while Fragallah [16] and the Lima study use ENVI-Met simulations to evaluate specific materials and interventions. El Nabawi et al. [17] integrates microclimatic data with subjective comfort assessments for a nuanced understanding of thermal comfort. Implementation.

All studies acknowledge the practical challenges in implementing these strategies, highlighting the need for affordability, community involvement, and further research to optimize and adapt interventions to local conditions. The interventions mostly used by these experts were developing climate-adaptive designs that are context-specific, particularly for informal urban areas in hot arid climates, as demonstrated by Lotfata while considering local socio-political, economic, and environmental conditions to ensure feasibility and effectiveness. Combining green infrastructure with cool materials to achieve synergistic benefits in mitigating the urban heat island [UHI] effect and improving thermal comfort, as evidenced by the Lima study. This combined approach maximizes temperature reductions and enhances urban livability and focusing on the use of affordable and easily maintainable interventions, such as light-colored paints, cool surface materials, and permeable ground covers, to ensure the practical implementation of climate-adaptive designs while cost-intensive solutions that may not be feasible in high-density informal urban areas.

1.4 Selection of Climate responsive streetscape interventions

As per the data collected during case study analysis, the interventions widely used in hot arid climates Here are the key elements that define a climate responsive streetscape in hot arid climates. By planting drought resistant trees and shrubs to provide natural shade. Installing pergolas, canopies, and other structures to create shaded walkways and seating areas. The use of materials with high solar reflectance [albedo] to reduce heat absorption. Concrete pavements can be most reflective if concrete is mixed with whitish cementitious materials. White cement is more expensive than grey cement concrete. The albedo of the most reflective white cement concrete is 0.18–0.39 superior to the highly reflective grey cement concrete. [18]. Applying reflective coatings to building surfaces adjacent to streets to minimize heat retention. Incorporating green belts and strips along streets to reduce heat through evapotranspiration. Utilizing raised planters and green walls to add vegetation without occupying much space. Installing water features that can help cool the air through evaporation. Implementing misting systems in high pedestrian traffic areas to provide immediate cooling effects.

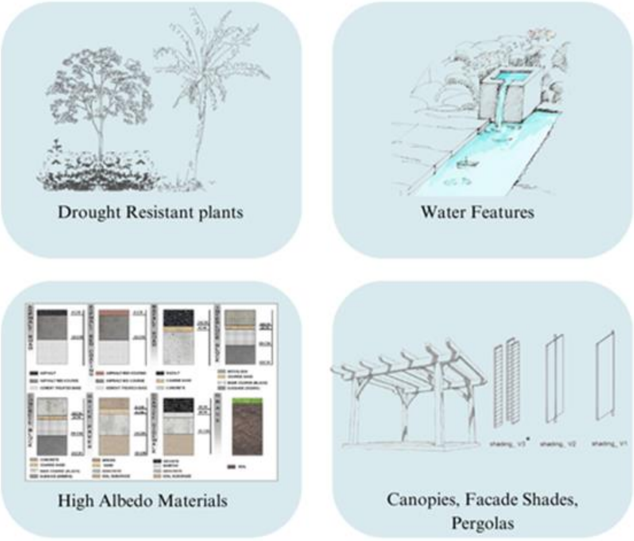

Figure 2. Diagram showing the Climate Responsive Streetscape interventions

Using permeable materials to allow water infiltration can cool the surface and reduce runoff. Permeable pavements are evolving as cool pavements and can be composed of concrete layers, turf or fired clay bricks which let air and water vapor into the voids of the pavement. Implementing pathways with materials that do not retain heat as much as traditional pavements.

By integrating these elements, a climate responsive streetscape in a hot arid climate can significantly enhance thermal comfort, reduce energy consumption, and improve the overall quality of life for urban residents. In Cairo, Egypt, the use of shading and vegetation as interventions in urban design has become a practical and sustainable solution due to the ongoing water scarcity issues the country faces. Water scarcity is a significant concern for Egypt, where over 90% of the population depends on the Nile River, which is increasingly under stress from population growth, pollution, and climate change. As a result, incorporating water-intensive elements such as fountains, ponds, or irrigated lawns in urban areas is becoming unsustainable. Instead, shading through trees, pergolas, and other vegetation offers a more water-efficient alternative, helping reduce the urban heat island effect, improve air quality, and provide cooler environments without the substantial water demand that would exacerbate the country’s water crisis. By focusing on drought-tolerant plants and utilizing shaded areas to promote comfort and well-being, Cairo can mitigate the impacts of extreme heat while addressing the urgent need for water conservation. This approach aligns with Egypt's broader sustainable development goals, emphasizing water-saving strategies and efficient resource management. [19]

2. MATERIALS AND METHODS

2.1 Case Study Selection

The case study examines the design and implementation of a climate responsive streetscape in Botros Ghaly street, focusing on how urban infrastructure can adapt to local climate conditions. By integrating sustainable design principles and innovative technologies, the project aims to enhance thermal comfort, mitigate heat island effects, and promote pedestrian friendly environments. Botros Ghaly street was selected for its multifunctional uses, the vibrant street used by locals throughout the entire day, can present a vital example for implying the climate responsive streetscape techniques. Boutros Ghali Street experiences high levels of urban heat due to the extensive use of asphalt, concrete, and limited green spaces. This makes it an appropriate site for studying the effectiveness of heat mitigation strategies. The street is also a vibrant public space with high pedestrian traffic. This allows for a thorough examination of how climatic responsive streetscape designs influence pedestrian behavior and comfort.

2.2 Data Collection

2.2.1 Study area Context

The initial research phase of the case study is crucial for understanding Botros Ghaly Street's environmental, social, and infrastructural conditions. It involves collecting data on climate factors like temperature, wind, and solar exposure, as well as demographic information, pedestrian traffic, and street usage through surveys and observations. Historical and planning documents provide context for urban development. This research establishes a baseline to guide the design of climate-responsive streetscape interventions aimed at enhancing thermal comfort and overall livability in the area.

Botros Ghali Street is a prominent street in the Roxy neighborhood, part of the Heliopolis district in Cairo. Named after the influential Ghali family, it reflects the area's rich political and cultural history. [20] Heliopolis, developed in the early 20th century by Belgian industrialist Baron Empain, was designed as a modern suburb with wide boulevards, green spaces, and a mix of European and Islamic architecture. Roxy became a commercial and social hub, attracting Cairo's middle and upper classes. Botros Ghali Street embodies this blend of modernity and tradition, with its elegant architecture, vibrant local businesses, and cultural significance as a gathering space for diverse communities.

Botros Ghali Street is well-connected through public transportation, including buses and metro stations, making it easily accessible for residents and tourists. Architecturally, the street features a blend of European and Egyptian motifs, reflecting Cairo's cosmopolitan nature in the early 20th century. The street is also a commercial hub in Roxy, home to various shops and cafes, fostering social interaction and a lively atmosphere. Despite modern changes, Botros Ghali Street remains a key part of Roxy's urban landscape, preserving its architectural heritage and symbolizing Egypt's modern history and cultural evolution.

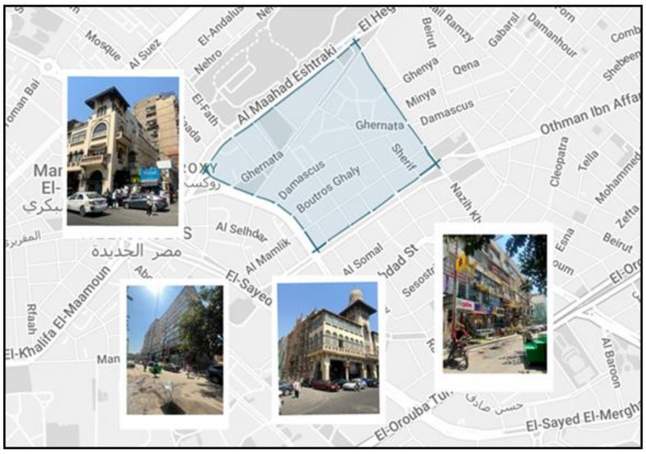

FIGURE 3. Layout showing Roxy District with pictures of Botros Ghali Street

2.2.2 Climatic Analysis

The 12 m wide street with length approx. 380 m long, however we will focus on the 180 m in the commercial zone. Location for the street is 30°05'33"N 31°19'13"E which means it has northeastern orientation. In Cairo, the summers are long, hot, humid, arid, and clear and the winters are cool, dry, and mostly clear. The hot season lasts for 4.6 months, from May 13 to October 1, with an average daily high temperature above 32°C. The hottest month of the year in Cairo is August, with an average high of 35°C and low of 24°C.

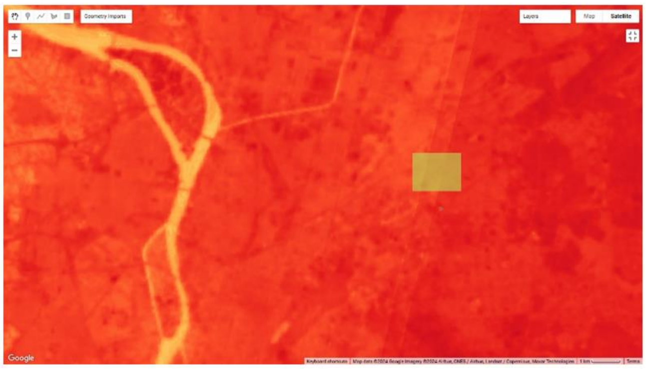

FIGURE 4. Roxy Area: its location within Cairo [left-hand side] and within the daytime surface urban heat island. LST was mapped using Google Earth Engine Open-Source Code [https://developers.google.com/earth-engine/datasets/tags/lst] for LST estimation.

The climatic analysis of Heliopolis shows that summer temperatures typically range between 34°C and 38°C but can peak at 40°C to 46°C, severely impacting thermal comfort. High humidity further exacerbates the heat by hindering the body's cooling process, resulting in a higher perceived temperature. In dense areas like Roxy, urban heat retention worsens the discomfort. Wind patterns, strongest in June, are affected by building height and vegetation, potentially creating an "urban canyon" effect, trapping heat and limiting ventilation.

2.2.3 Architectural and urban features

Botros Ghaly Street features buildings of varying heights, ranging from 24-28 meters for historical buildings to 48-56 meters for modern residential ones, allowing better airflow but also increasing sun exposure. The mix of stucco and plaster facades and modern glass-fronted commercial buildings contributes to the Urban Heat Island effect. Asphalt pavements with low reflectivity and sparse vegetation further worsen the thermal environment. Although pedestrian pathways are obstructed by vendors and the streetscape lacks greenery, there is potential for improvement through shading devices, green infrastructure, and permeable pavements.

After carrying out a survey with residents and users, The questionnaire's results underscore the community's need for a climate-responsive streetscape on Botros Ghaly Street. The data highlighted thermal discomfort during peak heat hours and identified shading, cooling materials, and ventilation as key design interventions. These findings will inform the next steps in the design process, ensuring that the implemented solutions address the real concerns and preferences of street users.

2.3 Simulation using FORMA

The design stage involves iterative steps to refine prototypes, addressing environmental, social, and aesthetic needs. Conceptual designs focus on mitigating sun exposure, heat gain, humidity, limited airflow, and pollution to improve outdoor thermal comfort. Autodesk Forma, a cloud-based tool, is used to analyze Botros Ghaly Street's urban design. It evaluates solar exposure, wind patterns, and thermal comfort to optimize the street's environmental performance and ensure climate responsiveness.

FIGURE 5. Layout of Boutros Ghali Street showing the vegetation along the street

2.3.1 Introduction of Forma

Autodesk Forma is a cloud-based platform for urban planning, architectural design, and environmental analysis. It offers tools to assess solar radiation, wind flow, thermal comfort, and energy use, helping optimize climate-responsive urban designs. Forma provides simulations to evaluate microclimates and pedestrian environments, focusing on solar and wind analyses. It integrates wind patterns with pedestrian comfort assessments using scales like Lawson 2001 and UTCI for thermal perception. However, it excludes surface material analysis, relying on weather data for accurate environmental predictions and insights. [21]

However, because Forma doesn't factor in water features or materials with high albedo (such as reflective surfaces), the simulation results may not fully reflect the cooling benefits these elements could contribute to real-world scenarios. Nonetheless, its focus on vegetation and shading provides valuable insights into landscape and architectural design strategies that reduce heat islands and enhance environmental sustainability.

2.3.2 Simulation of the Baseline Model

The baseline model of Botros Ghaly Street serves as the foundation for analyzing the street's current urban and environmental conditions using Autodesk Forma. This model provides a detailed representation of the street's physical characteristics, including buildings, street geometry, vegetation, and other relevant urban elements and ensuring that the model is accurately geolocated to match the real-world coordinates of Botros Ghaly Street. This allows Forma to simulate the street's interaction with actual solar and wind conditions. The purpose is to establish a reference point against which the impacts of proposed climate-responsive design interventions can be assessed.

2.3.3 Simulation of Prototype: Integration between Natural and Artificial interventions

By developing the prototype, the nature based, and artificial interventions derived from the case study analysis to create climate responsive streetscape designs. The prototype featured hybrid solutions, where vegetation and shading structures were combined to create cooler microclimates. For example, trees were strategically planted alongside adjustable canopies, which provided shade while allowing airflow. This hybrid approach aims to maximize the benefits of both natural and artificial shading, improve pedestrian comfort, enhance the urban environment, and contribute to energy efficiency.

Figure 6. Base Model Layout in Forma

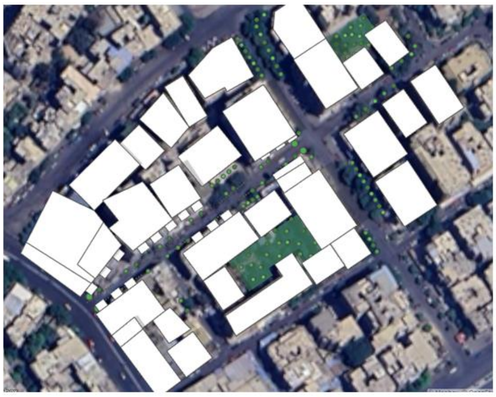

Figure 7. prototype after adding vegetation and shades along the street

2.4 Results

2.4.1 Initial Result

After running the sun exposure analysis during 15th of July it indicated that the ground for the street is subjected to long hours that average from 3 to 7 hours. Taking into consideration that the street cover is in asphalt, it would mean the street is subjected to higher heat gain and heat retention as mentioned, which will exacerbate the thermal discomfort. According to the Lawson comfort scale the wind comfort analysis indicates that 16% of the street area is considered comfortable to sit around, with a combined percentage of 84 of comfortable to stroll and stand. This is considered comfortable as the main function of the street is commercial with loads of people going through it. The wind analysis identified that the prevailing wind direction is from the northwest throughout most of the year. This wind pattern influences the placement of trees with specific patterns and spacing to allow the redirection of air flow and ensure the cross ventilation through the street. The analysis indicates higher wind speeds at the building corners and on the upper levels, where wind acceleration is more pronounced. These areas may experience discomfort during strong wind conditions, particularly during the winter months.

The higher buildings are considered in the direction of the prevailing wind, making the wind speed at street level very low which might cause discomfort and more heightened perception of temperature. According to the UTCI measured by forma, the users within the street experience 89% of severe distress and 11% of strong distress, meaning the crucial need for climate responsive streetscape for mitigation. The temperature within the ground level is at 40-44 °Care at 83% throughout July.

2.4.2 Prototype result

Integration between Natural and Artificial interventions

For the sun exposure analysis during 15th of July it indicated that the ground for the street after integrating natural interventions with the artificial shading devices reduced the area at the street levels and the hours exposed to the sun by significant 6-7%.

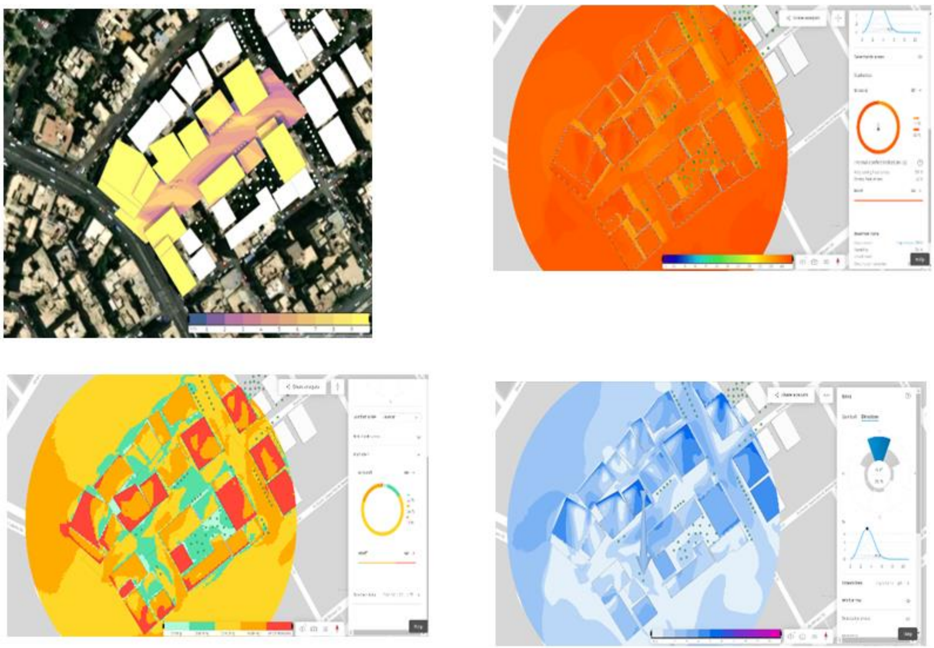

FIGURE 8. [A,B,C,D] A The layout [upper left] shows the Solar analysis, B [upper right] shows the thermal comfort index during july 15, C [lower left] shows the wind comfort analysis for performing activities, D [Lower right] shows the wind

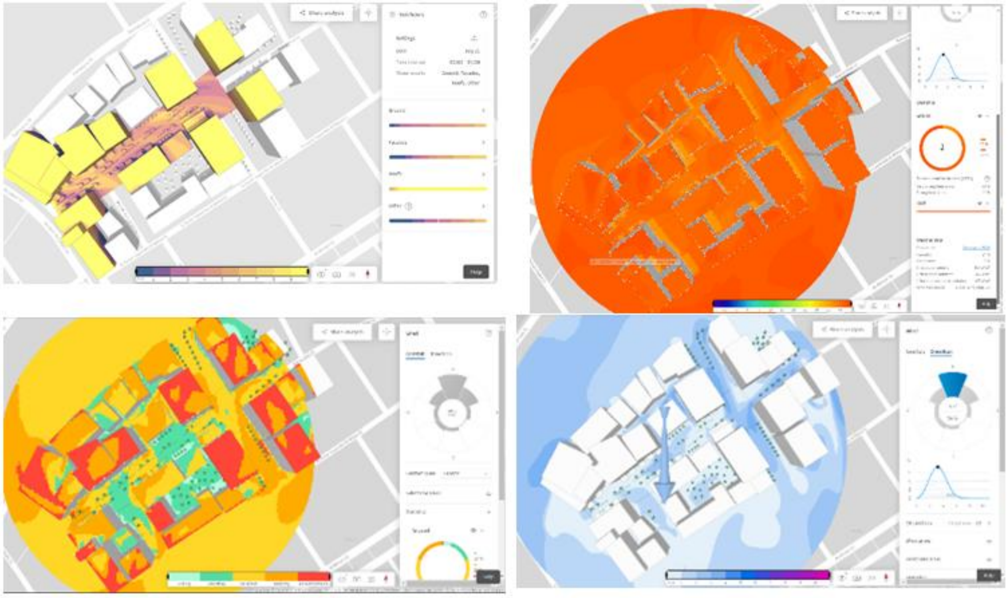

FIGURE 9. [A,B,C,D] A The layout [upper left] shows the Solar analysis, B [upper right] shows the thermal comfort index during july 15, C [lower left] shows the wind comfort analysis for performing activities, D [Lower right] shows the wind analysis, after adding vegetation and applying shades along

According to the Lawson comfort scale the wind comfort analysis indicates that 20% of the street area is considered comfortable to sit around, increasing 4% compared to baseline model, with a combined percentage of 81% of comfortable to stroll and stand. Shadings implemented along the street and facades integrated with planters across the pathways affected the wind speed in the northeastern direction, increasing the wind speed to 4% through the street along the day. According to the UTCI measured by forma, the users within the street experience 85% of severe distress and 15% of strong distress, meaning a reduction in the heat distress percentage from the baseline model by 5%, with significant reduction in temperatures ranging above 40 °Cfor 79% of the month and 21% of the month reaching to 35 C.

3. DISCUSSION

This section discusses the results of the simulation carried out after the implementation of the interventions.

The integration of trees and shading devices has significantly increased the number of shaded areas along the street. The combination effectively blocks direct sunlight during peak hours, particularly on sidewalks and public spaces, resulting in cooler ground temperatures and enhanced comfort for pedestrians.

Trees offer indirect shade that complements fixed shading structures like canopies and awnings, creating synergistic shading. Together, they make sure that spaces get enough shade while still letting in filtered natural light, which results in a cozy and aesthetically pleasing atmosphere. Trees placed next to sidewalks with canopies, for instance, provide shade during the hottest portions of the day while still letting in some light in the morning and late afternoon.

Buildings along the street benefit from reduced solar exposure, particularly on southern and western façades where the combined shading of trees and structures minimizes heat gain. This reduction is expected to lower cooling loads during the summer months, potentially resulting in energy savings.

The combination of trees and shading structures has moderate wind speeds along the street. Trees act as natural windbreaks, reducing the intensity of wind at street level, while shading structures like canopies help redirect wind flow. This has resulted in a more comfortable environment, particularly in areas that previously experienced high wind speeds. The strategic placement of trees in conjunction with open-sided shading structures has helped maintain adequate air circulation while minimizing wind tunnel effects. This balance ensures that pedestrians experience gentle breezes without the discomfort of strong gusts, especially in areas with high foot traffic.

The hybrid solution has led to a marked reduction in surface temperatures, particularly on paved surfaces like sidewalks and plazas. The combination of tree canopy cover and shading structures significantly lowers the urban heat island effect, making the street noticeably cooler and more comfortable during the day. The perceived temperature for pedestrians has improved dramatically due to the combined cooling effects of shaded areas and vegetation. The natural cooling from trees, which release moisture through transpiration, complements the shade provided by structures, creating a microclimate that feels cooler by several degrees compared to unshaded areas.

Enhanced Thermal Comfort Zones: Key public spaces, such as seating areas, pedestrian crossings, and bus stops, have seen the most significant improvements in thermal comfort. These zones are now more inviting for outdoor activities, with reduced risks of heat stress during peak summer months. The implementation of hybrid solutions combining vegetation and shading structures along Botros Ghaly Street has proven effective in creating cooler, more comfortable microclimates. This approach has not only improved pedestrian comfort but also contributed to energy efficiency and enhanced the overall urban environment.

This analysis demonstrates the effectiveness of the hybrid approach in transforming Botros Ghaly Street into a more sustainable, comfortable, and attractive urban space. The results from this iteration provide a strong foundation for further refinement and expansion of similar solutions in other parts of the city. The design prototypes were adjusted to address practical concerns identified in the first iteration, such as reducing the need for water intensive vegetation in arid climates. Drought resistant plants to be chosen, and water collection systems were integrated into the design to sustainably manage irrigation needs.

3.1 Recommendations

Given Cairo's unique climate, characterized by extreme heat, limited rainfall, and rapid urbanization, it is crucial to design streetscapes that not only adapt to these conditions but also contribute to mitigating climate-related issues. This section outlines strategies to create more sustainable, comfortable, and resilient public spaces by integrating innovative design solutions, climate-sensitive materials, and urban greening initiatives. By prioritizing thermal comfort, reducing air pollution, and promoting energy efficiency, these recommendations will foster a more livable environment for both present and future generations. Through the implementation of these strategies, Cairo can improve its urban resilience and set an example for other cities in the region facing similar climate challenges.

Consider the seasonal performance of high albedo materials to ensure they provide benefits in cooler months without reducing solar gain. Monitor wind patterns to prevent excessive wind or turbulence from reflective materials. Explore de-paving in less critical vehicle areas to create more green spaces, improving wind flow and pedestrian comfort. Expand high albedo materials in areas with heat retention issues, like parking zones. Monitor the long-term performance of reflective materials for effective cooling. Integrate water-sensitive urban design elements, such as rain gardens, to enhance sustainability and aesthetics. Engage the community for feedback on design changes. Incorporate climatic responsive streetscape design into urban planning policies and educate residents on green infrastructure benefits. Future projects should prioritize water-sensitive design, focusing on water recycling and efficient irrigation.

4. CONCLUSION

In conclusion, this paper emphasizes the detrimental effects of the Urban Heat Island [UHI] on public spaces in Cairo, especially in dense neighborhoods. Through a literature review and case study analysis, various climate-responsive streetscape interventions such as shading, vegetation, and high-albedo materials were identified as key strategies to enhance outdoor thermal comfort in hot arid climates. The simulation of Botros Ghaly Street using Autodesk Forma confirmed the effectiveness of these measures, demonstrating significant temperature reductions and improved pedestrian comfort. Future research should focus on refining and scaling these interventions to optimize urban resilience in different typologies of Streets and neighborhoods.

REFERENCES

[1] Effects of landscape composition and pattern on land surface temperature: An urban heat island study in the megacities of Southeast Asia. Ronald C. Estoque, Yuji Murayama, Soe W. Myint. 2017, Science of The Total Environment, pp. 349-359.

[2] Urban Heat Island and Its Impacts on Energy Consumption in Greater Cairo, Egypt. Abdel-Ghany, A. M., & Al-Dababat, T. s.l. : Sustainability, 2020, Vol. 12[9].

[3] Analysis of the Long-Term Trend of Land Surface Temperature and Urban Heat Island Effect in Greater Cairo. El-Askary, H., El-Bastawesy, M., & Allam, M. 9[6], 588., 2017, Vol. Remote Sensing.

[4] Impact of Urban Heat Island Phenomenon on Residential Buildings Energy Consumption in Greater Cairo, Egypt. . El-Zafarany, M. M., & Gomaa, M. 44, 2019, Vol. Sustainable Cities and Society.

[5] The Streets of Islamic Cairo: Urban Space and Social Practice. El-Kholei, A. 3, 2015, Middle Eastern Studies, Vol. 51, pp. 321-340.

[6] Urban Planning Challenges in Cairo: Strategies for Sustainable Development. El-Sheikh, A., & Saleh, M. 2, 2024, Journal of Urban Planning and Development, 140[2] , Vol. 140, pp. 130-145.

[7] Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. Ali Toudert, F., & Mayer, H. 2, 2006, Building and Environment, Vol. 41.

[8] Influence of urban morphology and sea breeze on hot humid microclimate: The case of Colombo, Sri Lanka . Emmanuel, R., & Johansson, E. 3, 2006, Climate Research, Vol. 30.

[9] A comprehensive review of outdoor thermal comfort in urban areas: Effective parameters and approaches. Reihaneh Aghamolaei, Mohammad Mehdi Azizi, Behnaz Aminzadeh and James O'Donnell. 6, 2023, Energy & Environment, Vol. 34.

[10] Designing Open Spaces in the Urban Environment: A Bioclimatic Approach. Nikolopoulou, M. [Ed.]. 2004.

[11] Reasons to adapt to urban heat [in The Netherlands]. Klok, L. and Kluck, J. 2018, pp. 342–351.

[12] On the use of bioclimatic architecture principles in order to improve thermal comfort conditions in outdoor spaces. Gaitani, N., Mihalakakou, G. and Santamouris, M. 2007, Build. Environ, pp. 317–324.

[13] Convivial Greenstreets: A Concept for Climate-Responsive Urban Design. Ken Tamminga, João Cortesão, Michiel Bakx. 2020, Sustainabilty .

[14] Designing thermally sensitive public spaces: an analysis through urban design media. Requena-Ruiz, Ignacio & Siret, Daniel & STAVROPULOS-LAFFAILLE, Xenia & Leduc, Thomas. 2022.

[15] Climate adaptation in Informal Areas in Hot Arid Climates. Lotfata, Aynaz & Cortesão, João & Zinsmeister, Hestia & Steeneveld, Gert-Jan & van Zeben, Josephine & taylor, zac & Tan, Wendy & Elkhateeb, Samah. [2023]. s.l. : Sustainable Development, 2023, Vol. 10.

[16] Evaluation of thermal comfort and urban heat island through cool paving materials using ENVI-Met. Riham Nady Faragallah, Riham A. Ragheb. 3, 2022, Ain Shams Engineering Journal, Vol. 13.

[17] Outdoor Thermal Comfort: Coupling Microclimatic Parameters with Subjective Thermal Assessment to Design Urban Performative Spaces. Mohamed H. Elnabawi, Neveen Hamza. 2020, Buildings.

[18] A review on the development of cool pavements to mitigate urban heat island effect. Qin, Yinghong. 2015, Renewable and Sustainable Energy Reviews.

[19] Moussadek, K. (2021). "Water conservation in urban environments: A case study of Cairo." Water Resources Management, 45(4), 847-860.

[20] CAPMAS. [Online] 2017.
https://censusinfo.capmas.gov.eg/Metadata-ar-v4.2/index.php/catalog/General_Statistics.

[21] Autodesk.[Online]2023.
https://www.autodesk.com/learn/ondemand/course/conceptual-design-with-autodesk-forma.