

Enhancing User Experience through Outdoor Recreational Spaces in Contemporary Shopping Malls

Njoku Prisca Chisomaga., Chinwennwo Philip Ohochuku., Anthony Enwin Dornubari

Department Of Architecture, Rivers State University, Pmb 5080, Nkpolu-Oroworukwo, Port Hacourt, Nigeria

DOI: <https://doi.org/10.51584/IJRIAS.2026.11060280>

Received: 01 July 2026; Accepted: 06 July 2026; Published: 18 July 2026

ABSTRACT

Shopping malls are transforming from conventional retail spaces into versatile environments that encourage leisure activities, socializing, and engaging experiences. In several Nigerian cities, including Port Harcourt, shopping malls predominantly focus on interior spaces, often neglecting the integration of outdoor recreational areas. This study investigates how the incorporation of outdoor spaces can enhance the user experience and transform the role of malls in urban landscapes. The study adopts a qualitative case study approach, analyzing three shopping malls: Novare Gateway Mall in Nigeria, Ikeja City Mall in Nigeria, Serramar Parque Shopping in Brazil. These case studies were selected to represent different typologies of shopping mall design, ranging from enclosed retail environments to fully integrated open-air and mixed-use developments. Data was obtained through architectural literature, design documentation, and relevant scholarly sources. Findings from the study reveal that shopping malls with well-integrated outdoor recreational spaces provide significantly improved user experiences characterized by comfort, relaxation, and engagement. Such spaces also encourage social interaction by serving as informal gathering points and venues for cultural activities. In contrast, malls with limited or no outdoor recreational spaces tend to offer more transactional and less engaging user experiences. The study concludes that outdoor recreational spaces should be considered essential components of contemporary shopping mall design rather than supplementary features. Their integration enhances experiential quality, strengthens social relevance, and supports sustainable architectural practices. The research recommends that future shopping mall developments, particularly in tropical urban contexts such as Nigeria, adopt climate-responsive and biophilic design strategies to create more inclusive, adaptable, and environmentally responsive retail environments.

Keywords: shopping mall, outdoor recreational spaces, experiential retail, user experience, public space integration.

INTRODUCTION

Traditionally, shopping centers have been conceptualized as enclosed environments intended to optimize store performance and control customer movement. However, recent studies indicate a shift toward experience oriented retail spaces, where comfort and spatial quality significantly influence customer satisfaction (Zhang et al., 2024).

The necessity for centralized retail spaces, which are frequently defined by inward facing layouts and climate-controlled interiors, gave rise to the conventional shopping mall model. Efficiency and consumption were given priority in these designs, often at the price of user engagement. Although these methods worked well in the past, they are now increasingly insufficient to meet the expectations of modern users.

For example, recent studies on malls in tropical regions show that although many establishments have rudimentary circulation and management systems, they frequently lack essential elements that improve user comfort and engagement, like outdoor areas and environmental integration (Adebayo et al., 2026).

The growing needs of entertainment, health and wellness, fashion, tourism etc have influenced the designs and various concepts/themes of shopping mall designs worldwide (Elliott & Anthony, 2020). Outdoor recreational

spaces have consequently gained renewed importance as essential features that support public health while maintaining economic activity. This shift has prompted architects and planners to reconsider the spatial organization of malls, favoring hybrid configurations that seamlessly blend indoor and outdoor environments.

In rapidly urbanizing regions such as Nigeria and other parts of sub-Saharan Africa, the integration of outdoor recreational spaces in shopping malls holds particular significance. By incorporating accessible and inclusive outdoor spaces, shopping malls can contribute to urban liveability, social cohesion, and environmental resilience. This is especially relevant in cities where climatic conditions such as high temperatures and seasonal rainfall necessitate thoughtful design strategies to ensure comfort and usability. From an architectural perspective, integrating outdoor recreational spaces requires a multidisciplinary approach that considers site context, climate responsiveness, spatial connectivity, and user behaviour. Designers must address challenges such as thermal comfort, shading, landscape maintenance, security, and the seamless transition between indoor and outdoor zones. In shopping malls, user experience is shaped by several factors, including circulation efficiency, spatial layout, ambiance, and the availability of amenities. (Douglas et al., 2025).

Information About The Study Area

Rivers state is located in the Niger Delta region of Southern Nigeria. Established on May 27, 1967. Rivers State shares boundaries with Bayelsa and Delta to the west, Abia and Akwa Ibom to the east, and Imo and Anambra to the north. Port Harcourt, the state capital, is regarded as the commercial hub of Nigeria's oil sector.

Situated on the ocean ward extension of the Benue Trough in the eastern portion of the Niger Delta, Rivers State is a largely low-lying pluvial state in southern Nigeria. Tropical rainforest covers the state's interior, but numerous mangrove swamps may be found along the coast in the characteristic Niger Delta climate. Rivers State is the 26th largest state in Nigeria, with a total area of 11,077 km² (4,277 sq mi).

Port Harcourt is the largest city and capital of Rivers state. After Lagos, Kano, Ibadan, and Benin, it is the fifth most populated city in Nigeria. It is situated in the oil-rich Niger Delta and runs alongside the Bonny River. The urban population of Port Harcourt is estimated to be 3,480,000 as of 2023. According to a 2015 United Nations estimate of 2,344,000, the population of the Port Harcourt metropolitan region is nearly double that of the urban area. There were 59,752 people living in Port Harcourt in 1950. Since 2015, Port Harcourt has expanded by 150,844, or 4.99% annually.

Climatic Data Of The Study Area

Temperature patterns do vary with the seasons. In winter, the time of minimum and maximum temperatures can shift slightly compared to summer.

- I. The months of June, July, August and September have nice average temperatures.
- II. On average the temperatures are always high.
- III. On average the warmest month is February with 34°C.
- IV. On average the coolest month is July with 29°C.
- V. The average annual maximum temperature is 31°C.
- VI. The average annual minimum temperature is 24°C.

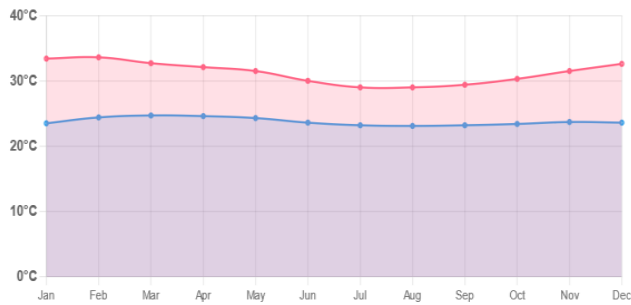


Figure 1: average minimum and maximum temperature in port harcourt.

Source: weather-and-climate.com

Rainfall

The month with the highest rainfall is **JULY** (293mm). The driest month (with the least rainfall) is **DECEMBER** (45mm).



Figure 2: average minimum and maximum rainfall in port harcourt.

Source: weather-and-climate.com

Humidity

On average, August is the most humid month, at 82.0%.

On average, January is the least humid month, at 55.0%.

The average annual percentage of humidity is 71%.



Figure 3: average minimum and maximum humidity in port harcourt.

Source: weather-and-climate.com

Statement Of The Problem

Despite the global trend toward immersive retail spaces. Many Port Harcourt commercial centers are still inward-looking and physically restrictive, Lack of well-integrated outdoor and recreational areas decreases user involvement overall and restricts social contact chances. Because of this, these shopping centers find it difficult to operate as vibrant social spaces in an urban setting. Therefore, there is need to integrate outdoor recreational spaces in shopping mall design. Hence the need for this research.

Aim

The aim of this study is to examine the integration of outdoor recreational spaces in shopping malls, to enhance user experience, promote social interaction, and improve the environmental and spatial quality of retail environments.

Objectives

- I. To evaluate the role and impact of outdoor recreational spaces in shopping malls.
- II. To identify and analyze architectural design strategies for effectively integrating outdoor recreational spaces in shopping mall developments.

Research Questions

- I. What is the role of outdoor recreational spaces in shopping malls?
- II. What architectural design strategies can be employed to effectively integrate outdoor recreational spaces in shopping mall developments?

LITERATURE REVIEW

The conceptual framework for this study is anchored on the intersection of two key concepts: experiential retail and public space integration. These concepts collectively explain how outdoor recreational spaces function within shopping malls and how they contribute to user satisfaction. The availability of social spaces, environmental quality, and spatial configuration all influence the user experience at shopping malls. According to a study by Erdoğan et al. (2023), consumers increasingly prefer open and semi-open shopping spaces because they believe they are more comfortable, fresh, and connected to their surroundings. It has also been demonstrated that integration of outdoor recreational spaces and green areas greatly enhances user experience. According to research on shopping mall environments, elements like courtyards, landscaped areas, and semi-open spaces promote social interaction, psychological comfort, and longer stay periods (Sharma & Gupta, 2024). Additionally, new studies emphasize how crucial human centered design is in retail spaces. To create places that are both sustainable and engaging, spatial features that integrate landscape elements, cultural relevance, and user-oriented design techniques are crucial (Li et al., 2025).

Emperical Framework

Literature studies were conducted by (Chuloh Jung et al., 2023) to extract evaluation factors, such as comfort, aesthetics, convenience, and accessibility for rest areas adjacent to the escalator, restroom, open corridor, and outdoor locations. An empirical study was then carried out, where field observations and user-satisfaction surveys were conducted in the indoor and outdoor rest areas of three prominent malls, namely the Dubai Mall, Dubai Festival City, and Mirdif City Center. The results of the study indicate that in open-corridor rest areas, easy access was highly rated in the satisfaction survey, while noise and privacy maintenance received lower ratings. Comparatively, outdoor rest areas scored higher on the satisfaction survey than indoor rest areas, such as the rest area next to the escalator, open-corridor rest area, and rest area next to the bathroom.

A larger post-COVID survey of 586 users across nine Turkish shopping centres similarly found that outdoor and semi-outdoor centres are likely to be preferred more often, with stronger demand for plants and water features. (Özlem Nur Aslantamer et al., 2024) conducted an online survey with 586 randomly selected users across nine shopping centers located in three major cities of Turkey: Istanbul, Ankara, and Izmir, with three shopping centers in each city. The survey investigated users' preferences for architectural styles (indoor, semi-outdoor, or outdoor) and landscape design in shopping centers. The findings of the study indicate that post-pandemic, outdoor and semi-outdoor shopping centers are likely to be preferred more frequently.

Experiential Retail In Shopping Malls

Experiential retail refers to the design of commercial environments that prioritize customer experience over mere product acquisition. Modern shopping malls are increasingly conceived as lifestyle destinations that combine retail with entertainment, leisure, and social activities (Kim & Lee, 2021). This shift is largely driven by competition from e-commerce platforms, which has forced physical retail spaces to offer unique, immersive experiences that cannot be replicated online (Pantano et al., 2020). Outdoor recreational spaces play a central role in experiential retail by providing dynamic environments where users can engage in activities beyond shopping. Features such as open plazas, performance spaces, and landscaped gardens encourage longer visits and repeated patronage. These spaces transform malls into social hubs, thereby increasing their relevance in contemporary urban life. In many developing countries, malls serve as safe, accessible environments for social interaction, leisure, and community activities (Adebayo & Akinyemi, 2023).

Outdoor Recreational Spaces In Shopping Malls

Outdoor recreational spaces within shopping malls refer to open-air environments designed to support leisure, relaxation, and social interaction. These spaces may include courtyards, rooftop terraces, landscaped gardens, playgrounds, and pedestrian promenades. Comfort, accessibility, and environmental quality all have a direct impact on how long people stay and how frequently they return in commercial settings (Oluwunmi et al., 2020). In the context of the built environment, user experience is shaped by spatial layout and ease of movement, environmental comfort (thermal, visual, acoustic), availability of recreational spaces and aesthetic qualities. Open seating areas, courtyards, and landscaped areas are examples of outdoor recreational spaces that significantly influence user experience. The following crucial elements help to understand their impact:

Environmental comfort

Particularly in tropical regions like Nigeria, outdoor areas can greatly enhance thermal and physical comfort. Characteristics like trees and shading devices help to enhance air quality and reduce heat. Studies conducted in Nigerian retail settings reveal that consumers are happier in areas with improved air quality and temperature than in completely enclosed locations (Adebayo & Adebisi, 2021).

Spatial experience

Outdoor recreational areas enhance connectivity and spatial clarity by:

Breaking the monotony of enclosed hallways

Establishing visual landmarks

Improving orientation

Clear circulation and visual access enhance user navigation and lessen confusion, according to spatial studies conducted in Nigerian commercial centres (Adeyemi & Jimoh, 2020).

Social interaction and engagement

Shopping centres now serve as social places in addition to commercial ones. Outdoor spaces promote social interaction and gatherings it also provide places for casual meetings and encourage recreational activities. According to a study on urban public spaces in Nigeria accessible and open spaces foster social cohesiveness and user involvement, particularly among young people (Nnadi & Oluwunmi, 2022).

Dwell time

Outdoor recreation areas motivate people to go to the mall more often, take part in activities other than shopping.

This is significant because greater economic activity and user satisfaction are strongly correlated with longer dwell times. Comfortable and interesting settings increase customer retention and repeat visits (Oluwunmi et al., 2020).

Design Strategies That Can Be Employed

- I. Plaza Spaces
- II. Landscaped Gardens
- III. Dining Terraces
- IV. Event and Performance Spaces
- V. Rooftop Recreational Spaces
- VI. Children play areas

Gap

While internal spatial organization and retail efficiency have been the subject of much research, little attention has been paid to how outdoor recreational areas might improve user experience in shopping malls in Port Harcourt. By suggesting design approaches that adapt to socioeconomic factors, this study aims to close this gap.

METHODOLOGY

This study adopts a post positivist, mixed-methods methodology, to examine how outdoor recreational spaces enhance user experience in contemporary shopping malls. The research design is a comparative multiple case study.

The chosen shopping malls are selected based on the following criteria:

- I. Incorporation of outdoor design elements
- II. Relevance to user experience
- III. Availability of data
- IV. Diversity in design approach

Case Studies

Three contemporary shopping malls were purposively selected based on varying levels of outdoor recreational provision: low, moderate, moderate, and high. This comparative structure allows for cross-case analysis of the influence of recreation on spatial performance and user behaviour.

Case Study 1: Novare Gateway Mall

Novare Gateway Mall is located along the Airport Expressway (Musa Yar'Adua Expressway) in Lugbe, Abuja, Federal Capital Territory, Nigeria. The mall occupies a strategic position on one of the busiest transportation corridors connecting Abuja city centre with the Nnamdi Azikiwe International Airport.



Figure 4: Approach view of Novare Gateway Mall

Source: novare-gateway.com



Figure 5: floor plan of Novare Gateway Mall

Source: novare-gateway.com

The mall adopts an integrated linear-loop layout. Unlike traditional enclosed malls with rigid corridor systems, Novare Gateway Mall utilizes broad circulation corridors that connect major retail destinations while creating visual openness.

Case Study 2: Ikeja City Mall

The Ikeja Mall is a contemporary, straightforward mall with roughly 64 stores, air conditioning, and plenty of outdoor parking. The Ikeja city mall is located at Alausa in Ikeja, Lagos state Nigeria. Aluminium, glass, natural stone, and paint are used to finish the complex's exterior. The facility has two entrances for entry and departure. It was constructed on 28,500 square meters of ground near the Lagos State Secretariat in Alausa, Ikeja, Lagos.



Figure 6: Approach view of Ikeja City Mall

Source: photobucket, 2019.



Figure 7: ground floor plan of Ikeja City Mall

Source: photobucket, 2019.

The shopping centre has a supermarket and a 5-screen Silverbird movie theatre, which is Ikeja's first and only movie theatre. Department stores, banks, cafes, bars, restaurants, hair salons, and ice skating arenas are all included.

The facility has 96 stores in total, and its leasable area is 250,000 square feet (250,000 square feet). To create foot flow for the smaller, less noticeable store, the mall has three large anchor tenants just after each strip of inline stores.

Case Study 3: Serramar Paque Shopping Mall

The serramar paque shopping mall is located in Carcaguatuba, São Paulo, Brazil

It has approximately 20,000 sqm of gross floor area with 100 stores, including anchor shops and retail stores, besides a supermarket, a home center, and food court with fast food and family restaurants, four cinemas and 1000 parking spaces.



Figure 8: Approach view of serramar paque mall

Source: Arch daily

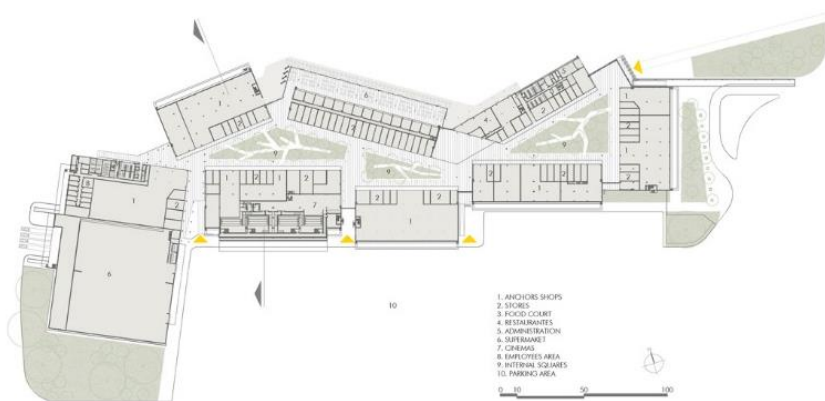


Figure 9: floor plan of serramar paque mall

Source: Arch daily

The mall was intended to blend in with the surrounding environment. Unlike the typical retail mall design, which is usually enclosed, the goal was to create an open space concept that connects with nature. To create a beach-like atmosphere, the food court was opened outside the mall with protruding bamboo canopies.

RESULTS AND DISCUSSIONS

This chapter synthesizes findings from the three case studies Novare Gateway Mall, Ikeja Shopping Mall and Serramar Parque Shopping Mall to critically evaluate how outdoor recreational spaces influence user experience, social interaction, and environmental performance in shopping malls. The analysis is structured in line with the research objectives and questions, focusing on key thematic areas.

Level of integration of outdoor recreational spaces

A clear variation exists in the degree to which outdoor recreational spaces are integrated across the case studies.

Novare Gateway Mall demonstrates minimal integration, with outdoor areas largely restricted to circulation and parking. These spaces are not designed for user engagement or leisure.

Ikeja Shopping mall reflects little recreational integration, embedding just internal recreational spaces, limiting the mall to just retail use.

Serramar Parque Shopping exhibits full integration, where outdoor spaces are central to the design concept, forming the primary circulation and interaction zones.

Promotion of social interaction

The ability of shopping malls to function as social spaces is closely tied to their outdoor design.

Novare Gateway mall has limited opportunities for social interaction outside commercial activities due to lack of gathering spaces.

Ikeja shopping mall poorly supports both informal and organized social activities, including events and public gatherings.

Serramar shopping encourages informal social interactions through seating areas, and open play area.

Spatial connectivity and circulation

The relationship between indoor and outdoor spaces affects movement and accessibility.

Novare Gateway mall features rigid, inward focused circulation, limiting spatial diversity.

Ikeja shopping mall offers more inward focused connectivity, making it difficult to link the mall to outdoor spaces.

Serramar shopping mall offers fluid circulation, with outdoor spaces acting as connectors between retail units.

Economic implication

The integration of outdoor spaces also has economic implications:

Novare Gateway mall relies solely on retail transactions for revenue generation.

Ikeja city mall relies solely on retail transactions for revenue generation and dwell time.

Serramar shopping mall benefits from increased dwell time and user engagement, which can boost spending. It attracts a diverse user base, including tourists and non-shoppers, expanding economic opportunities.

Outdoor recreational spaces plays a great role in improving the overall user experience in a shopping mall. It improves user experience by: reducing the spatial monotony associated with enclosed malls, introducing environmental variation (light, air, scenery) and offering areas for rest and relaxation.

The combination of natural materials, open-air walkways, and planted courtyards at Serramar Parque shopping mall offers a multisensory space where users may enjoy natural light, ventilation, and a visual connection to greenery. This stands in contrast to Port Harcourt mall and Ikeja City mall, where the enclosed layout makes for a less exciting and less stimulating experience.

Climate responsive design strategies can be incorporated to improve user experience. These strategies may include:

- I. Use of shading elements (trees, canopies, pergolas)
- II. Integration of green areas
- III. Orientation for natural airflow

Outdoor recreational spaces significantly enhance social interaction in a shopping mall by providing neutral grounds for social engagement, encouraging longer dwell time and repeated visits, supporting cultural and community activities.

Courtyards and seating sections in Serramar shopping mall serve as unofficial social hubs that encourage people to gather and engage.

On the other hand, Novare Gateway Mall and Ikeja City mall lack defined outdoor recreational spaces which restricts the opportunity of interaction beyond commercial activities.

Flexible design strategies can be incorporated to improve social interaction in a shopping mall. Effective outdoor spaces should be flexible for multiple uses.

These strategies may include:

- I. Event areas and seating sections
- II. Children play areas
- III. Plaza spaces

From the analysis, several key findings emerge:

- I. Outdoor recreational spaces significantly enhance user experience by providing comfort, variety, and opportunities for relaxation.
- II. They promote social interaction, transforming malls into community oriented spaces.
- III. They improve environmental performance through passive design strategies.
- IV. They enhance spatial connectivity, creating more dynamic and flexible environments.
- V. They contribute to economic viability by increasing dwell time and attracting diverse users.

CONCLUSION

The study concludes that integrating outdoor recreational spaces into shopping mall design is essential for creating sustainable, user centred, and socially responsive retail environments. The traditional enclosed mall typology, as observed in the Nigerian case studies, is increasingly inadequate in meeting contemporary user expectations for experience, comfort, and social engagement. International case study demonstrate that when outdoor recreational spaces are thoughtfully designed and integrated, they transform shopping malls into multifunctional environments that combine retail, leisure, culture, and nature. These spaces not only enhance user experience but also contribute to environmental sustainability and urban livability. Therefore, the integration of outdoor recreational spaces should not be treated as an optional design feature but as a fundamental component of modern shopping mall architecture.

RECOMMENDATIONS

Based on the findings of the study, the following recommendations are proposed:

- I. **Intentional design of outdoor spaces:** Outdoor recreational spaces should be deliberately designed as part of the overall architectural concept rather than treated as leftover or residual spaces.
- II. **Creation of flexible social spaces:** Outdoor areas should be designed to support multiple functions, including relaxation, events, cultural activities, and informal gatherings.

- III. **Integration with urban context:** Shopping malls should be designed as extensions of the urban fabric, allowing seamless interaction between private retail spaces and public outdoor environments.
- IV. **Climate responsive design strategies:** In tropical regions like Nigeria, designers should prioritize passive cooling strategies such as shading devices, landscaping, cross-ventilation, and open courtyards.

REFERENCES

1. Adebayo, P., & Akinyemi, A. (2023). Urban retail development and public space provision in Nigerian cities. *Journal of African Urban Studies*, 8(2), 45–60.
2. Adebayo, A., Olagunju, R., & Adeyemi, O. (2026). Exploring the sustainability performance of shopping malls in tropical environments. *Journal of Sustainable Built Environment*, 15(2), 145–162.
3. Adebayo, A., & Adebisi, K. (2021). Thermal comfort and user satisfaction in commercial buildings in Nigeria. *Journal of Environmental Design and Management*, 13(2), 45–58.
4. Adeyemi, E., & Jimoh, R. (2020). Spatial organization and user movement in commercial centers in Lagos. *Nigerian Journal of Architecture*, 9(1), 23–34.
5. Chuloh Jung, Naglaa Sami Abdelaziz Mahmoud 2023. Exploring Customer Behavior in Shopping Malls: A Study of Rest Areas in Dubai, United Arab Emirates <https://doi.org/10.3390/su15129169>
6. Douglas, k., Ogunnaike, A. O., & Fasintei, P. (2025). Perceptions of circulation and spatial layout efficiency in Ikeja City Mall.
7. Erdoğan, E., Yıldız, Z., & Erdoğan, H. A. (2023). User perceptions of shopping centres with different spatial configurations. *ICONARP International Journal of Architecture and Planning*, 11(1), 207–228. <https://doi.org/10.15320/ICONARP.2023.239>
8. Hami, A., Abdi, B., Zarehaghi, D., & Maulan, S. (2021). Assessing the effects of urban green spaces on users' mental health in shopping environments. *Urban Forestry & Urban Greening*, 62, 127–138. <https://doi.org/10.1016/j.ufug.2021.127138>
9. Ichoko, E., & Ewin, G. (2020, November 12). Impact of Architectural Design on Consumer behaviour- SPAR P.H. city. Retrieved from Free online Survey: <https://freeonlinesurveys.com/r/aRcbv5C2>
10. Kim, J., & Lee, H. (2021). Experiential value of shopping malls: The role of leisure and social interaction. *Journal of Retailing and Consumer Services*, 61, 102–115. <https://doi.org/10.1016/j.jretconser.2021.102115>
11. Li, X., Zhang, Y., & Wang, H. (2025). Human-centered design strategies for sustainable commercial architecture. *Sustainability*, 17(6), 2717. <https://doi.org/10.3390/su17062717>
12. Nnadi, E., & Oluwunmi, A. (2022). Public space usage and social interaction in urban Nigeria. *Covenant Journal of Research in the Built Environment*, 10(1), 67–80.
13. Oluwunmi, A., Durodola, O., & Ajayi, C. (2020). User satisfaction in shopping malls in Lagos, Nigeria. *Property Management*, 38(2), 231–245. <https://doi.org/10.1108/PM-07-2019-0045>
14. Özlem Nur Aslantamer, H. E. Ilgın 2024. Exploring the impact of landscape design on user preferences in shopping centers post the COVID-19 Pandemic <https://doi.org/10.47818/drarch.2024.v5i2125>
15. Pantano, E., Pizzi, G., Scarpi, D., & Dennis, C. (2020). Competing during a pandemic? Retailers' ups and downs during COVID-19 outbreak. *Journal of Business Research*, 116, 209–213. <https://doi.org/10.1016/j.jbusres.2020.05.037>
16. Sharma, P., & Gupta, R. (2024). The impact of green spaces on user experience in shopping malls. *International Journal of Multidisciplinary Research*, 6(7), 112–120.
17. Zhang, L., Chen, Q., & Liu, Y. (2024). Evaluating the impact of public space design on user satisfaction in shopping malls. *Buildings*, 14(10), 3264. <https://doi.org/10.3390/buildings14103264>
18. Zhong, W., Schröder, T., & Bekkering, H. (2022). Biophilic design in architecture: A review of the impact on human well-being. *Building and Environment*, 207, 108–134. <https://doi.org/10.1016/j.buildenv.2021.108134>