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Unveiling The Depths: Transforming An Abandoned Limestone Quarry Into A Tourism Destination in Takerghat, Sunamganj



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Abstract: Niladri Lake, located in the Takerghat region of Sunamganj, Bangladesh, is a quarry lake formed from an abandoned limestone quarry. Originally a site of industrial limestone extraction, it played a key role in the local and national economies by supplying the Chhatak Cement Factory. After mining had ceased, the quarry gradually filled up with water, eventually forming Niladri Lake. To understand the historical and geological significance of Niladri Lake, the research follows its evolution from an industrial site to a restored water body. The paper covers initiatives to revitalize the region and establish ecological balance by combining environmental awareness, geological heritage preservation, and sustainable tourism. This study uses field surveys, interviews, and impact assessments to explore Niladri Lake's potential for tourism, demonstrating how to restore post-industrial landscapes for environmental and community benefit. The findings emphasize the dynamic relationship between nature and industrial activity and offer significant insights for land reclamation and sustainable tourism development.

Keywords: Niladri Lake; Limestone; Quarry; Geological Heritage; Sustainable Tourism.

Derinlikleri Ortaya Çıkarmak: Terkedilmiş Bir Kireçtaşı Ocağının Takerghat, Sunamganj'da Turizm Noktasına Dönüştürülmesi

Özet: Bangladeş'in Sunamganj bölgesindeki Takerghat'ta yer alan Niladri Gölü, terkedilmiş bir kireçtaşı ocağından oluşan bir taş ocağı gölüdür. Başlangıçta endüstriyel kireçtaşı çıkarımı için kullanılan bu alan, Chhatak Çimento Fabrikasına tedarik sağlayarak yerel ve ulusal ekonomide önemli bir rol oynamıştır. Madencilik faaliyetlerinin sona ermesinin ardından ocak zamanla suyla dolarak Niladri Gölü'nü oluşturmuştur. Bu araştırma, Niladri Gölü'nün tarihsel ve jeolojik önemini anlamak amacıyla, onun endüstriyel bir alandan doğal bir su kütleline dönüşümünü incelemektedir. Çalışma, çevresel farkındalık, jeolojik mirasın korunması ve sürdürülebilir turizmin bir araya getirilmesi yoluyla bölgenin yeniden canlandırılması ve ekolojik dengenin sağlanması yönündeki girişimleri ele almaktadır. Araştırmada saha çalışmaları, görüşmeler ve etki değerlendirmeleri kullanılarak Niladri Gölü'nün turizm potansiyeli incelenmiş ve endüstri sonrası peyzajların çevresel ve toplumsal faydalar için nasıl geri kazanılabileceği gösterilmiştir. Bulgular, doğa ile endüstriyel faaliyetler arasındaki dinamik ilişkiyi vurgulamakta ve arazi ıslahı ile sürdürülebilir turizm geliştirme konusunda önemli çıkarımlar sunmaktadır.

Anahtar kelimeler: Niladri Gölü, Kireçtaşı, Taş Ocağı, Jeolojik Miras, Sürdürülebilir Turizm.

1. INTRODUCTION

In recent years, the concept of sustainable tourism development has gained global interest as communities aim to balance economic growth with environmental protection. The transformation of abandoned mining and industrial sites into tourist attractions presents a unique opportunity to restore degraded landscapes, maintain ecological integrity, and promote regional development. Based on both geographic and national significance, areas of abandoned quarries are a significant part of the environment. Quarries acquire intriguing morphological features, making them distinctive landmarks. Furthermore, it is vital to keep in mind that these locations have local cultural values and could be a key component of a tourist attraction [1].

With a focus on a destination's distinctive geological features, geotourism is a specialized form of tourism that seeks to give tourists sustainable and instructive experiences [2]. Traditional mining sites, rich in cultural, social, and geological heritage, offer significant potential for geotourism. These locations preserve the "historic signals" of ancient mining activities, connecting visitors to the Earth's geological processes and human history. Transforming such sites into geotourism destinations fosters heritage conservation, education, and sustainable local economic development [3].

Generally speaking, locations or regions with a substantial geoheritage have a particular responsibility to preserve the existing geological features for their significance on a national and worldwide level [4]. In this context, the abandoned limestone quarry at Takerghat, Sunamganj, emerges as a site of significant potential for sustainable redevelopment. Historically, Takerghat served as a center for the extraction of limestone, which was essential to the development of Bangladesh's infrastructure and industry. The quarry's limestone reserves were extensively mined, contributing to the production of cement and other construction materials. Post-industrial landscaping involves repurposing degraded or abandoned industrial sites to integrate them back into the environment and community. Quarry lakes, which develop when excavation pits fill with surface or groundwater after mining activities cease, are one of the most distinctive aspects of open-pit mining [5]. In comparison to the landscape's pre-operational state, these bodies of water reflect a significant and long-lasting change. The resulting quarry lake, named Niladri Lake in Takerghat, is a visually appealing feature as well as an environmentally significant asset, offering chances for sustainable tourism, ecological rehabilitation, and a celebration of the area's industrial past. Industrial heritage, which significantly contributed to human progress during the industrialization era, should be carefully preserved to ensure its transmission to future generations [6].

The site is now inert after decades of operation, with a landscape that echoes its industrial past, vast excavations, and abandoned infrastructure. In addition to leaving the region economically and environmentally stagnant, the end of mining activities has given rise to a chance to rethink its future through the growth of sustainable tourism. However, the region is severely limited by a lack of tourism-related activities, which limits its potential to provide tourists with intriguing and varied experiences. The tourism industry in Takerghat confronts challenges, including poor community engagement, environmental threats, a lack of diverse activities, and inadequate amenities. A comprehensive approach is required to solve issues, with a focus on low-impact, sustainable tourism, community-driven projects, and environmentally friendly facilities. This strategy promotes Takerghat's development as a sustainable tourism destination by ensuring long-term sustainability and resilience.

The main objectives of this study are to investigate educational possibilities, evaluate conservation strategies, encourage community engagement, and suggest eco-friendly tourism practices that protect the area's geological heritage. The research explores the types of mining and their environmental implications, focusing on the historical and present state of the Takerghat limestone quarry. Furthermore, the concept of

quarry lakes is examined, emphasizing their potential as important elements of tourism projects in terms of ecology, recreation, and aesthetics.

Various field studies will be conducted to gather data on the environmental, geological, and socio-economic aspects of the Niladri Lake area. The study proposes a thorough plan for revitalizing the Takerghat quarry, demonstrating how creative design, community engagement, and ecological practices can turn abandoned industrial sites into thriving tourist attractions. Supported by case studies of successful quarry rehabilitations, the research highlights strategies for balancing ecological restoration, cultural preservation, and economic growth tailored to Takerghat's unique context.

1.1 Historical Background of the Study Area

The Takerghat Limestone Mining Project, located in Sunamganj, Bangladesh, has a rich history rooted in industrial development. It was initiated in the middle of the 20th century to extract limestone, which is a key raw resource for construction and cement manufacturing. It supplies limestone to the Chhatak Cement Factory, enabling it to produce cement for both national and regional markets [7]. Because limestone from the Khasi Hills was locally calcined for the Bengali market during the British Raj, Chhatak gained importance in the limestone business. Utilizing limestone from the Khasi Hills and later Takerghat, the Assam Bengal Cement Factory was founded in 1940. The facility continues to be a major participant in the local cement market, underscoring the industrial significance of Chhatak. The history and development of the limestone mining project in Takerghat hold significant importance for Bangladesh's cement industry-

Local Resource Discovery: In 1961, geological surveys conducted in Takerghat verified that five drilled pits contained roughly 132.56 million metric tons of limestone. This finding revealed the possibility of domestic limestone extraction [8].

Initial Limestone Extraction: In the 327-acre Takerghat mining project area, formal operations started in 1965 and 1966. Two quarries, totaling 70.69 acres and 92.25 acres, respectively, were the first to extract limestone. By 1980, 1.66 million metric tons of limestone had been removed.

Mismanagement and Corruption: The project was managed by the Bangladesh Chemical Industries Corporation (BCIC), but it was allegedly brought to a halt by the dishonest actions of some authorities, workers, and self-interested labor union members. Allegedly, these acts were deliberate, transforming a once-profitable initiative into a losing industry.

Transfer to Chhatak Cement Factory: Later, the project was placed under the direction of another BCIC establishment, the Chhatak Cement Factory. Even after the transfer, the project's problems persisted, and by the middle of the 1990s, operations had drastically decreased.

Closure in 1996: The mining project was closed around 1996. About 400 employees were moved to other BCIC facilities. With this closure, the region's active limestone extraction came to an end.

Final Shutdown in 2007: On October 2, 2007, 31 officers and employees from the Chhatak Cement Factory were transferred, bringing an end to all project-related activities.

Given the substantial investment made in the project, equipment valued at over 60 crore BDT (Bangladeshi Taka) was underutilized at the time of closure. Following the end of mining operations, groundwater and rain slowly filled the abandoned quarry sites, forming Niladri Lake. This natural transformation turned the former industrial site into a beautiful lake, now a popular tourist destination. The story of the Takerghat limestone mining project is a tale of both industrial success and failure, marked by significant challenges

and a transformative environmental recovery. The transition from a profitable mining operation to a closed project due to mismanagement, followed by the natural formation of Niladri Lake, highlights the dynamic interplay between industrial activity, economic factors, and environmental processes. With its existing prominence as a tourist destination, Niladri Lake offers optimism for long-term economic growth based on the region's historical significance and scenic beauty.

1.2. Geology of the Study Area

The Sylhet-Assam region boasts a rich history of limestone mining, with quarrying in the Khasi hills beginning in the eighteenth century, making it a thriving business in Sylhet. The Takerghat Limestone Development and Transportation Project, spanning 237.93 acres, was initiated by the East Pakistan Industrial Development Corporation (EPIDC) in 1967 and subsequently managed by various entities, including the Bangladesh Industrial Development Corporation (BIDC), Bangladesh Mineral Exploration and Development Corporation (BMEDC), BCIC, and Chhatak Cement Company Ltd.

Takerghat, located in Sunamganj, contains Eocene limestone deposits that range from surface to near-surface levels, highlighting the area's geological significance. All near-surface extractable limestone deposits in the area have been mined using the open-pit method. Drilling has revealed that the remaining limestone exists as tilted and faulted blocks, dipping at angles of 45–75° toward the south [8]. The total reserves, extending from the surface to a depth of approximately 150 meters, are estimated to be around 14 million tons. The limestone is hard and compact, consisting of both fossiliferous and non-fossiliferous beds. In Bangladesh, the term “Sylhet Limestone” was introduced by Khan (1963) to describe the limestone deposits in Sylhet. The Eocene Limestone is stratigraphically located in the Sylhet Trough and shelf sections beneath the Kopili Formation and above the Tura/Cherra Formation. The earliest known outcrop of Tura sediment is found in the Takerghat region of Sunamganj. It dips southward from the southern margin of the Shillong Plateau and is faulted and folded [9]. The alternating layers of fine- to coarse-grained, cross-bedded sandstones in white, pink, and brown hues, as well as light gray shales, mudstones, and traces of carbonaceous material from the Tura Sandstone, support the limestone deposits in this area of the Sylhet Trough. Although the exact depth of the limestone is unknown, data from boreholes indicates that the beds' greatest thickness is roughly 61.0 meters [8].

1.3. Limestone Mining Scenario of the Study Area

The limestone extraction process at the Takerghat quarry was a comprehensive operation, combining open-pit mining with advanced equipment and techniques to maximize efficiency. The process began with the removal of surface layers, exposing the rich limestone deposits beneath [10]. These reserves were reached by drilling holes in the rock with massive drills and then filling those holes with dynamite. The large stone was subsequently crushed up into manageable pieces by controlled explosions. The depth of mining ranged from 80 to 500 feet, ensuring that significant reserves were extracted. Following the fragmentation of the limestone, the broken rock was transported to specified processing zones using heavy equipment like loaders and excavators. Here, the limestone underwent crushing to reduce it to smaller fragments suitable for industrial use. The limestone was then washed in specialized limestone washing pits to remove impurities, improving its quality. To make the limestone acceptable for a variety of uses, specifically the manufacturing of cement, it was screened after washing to divide it into different sizes and grades.

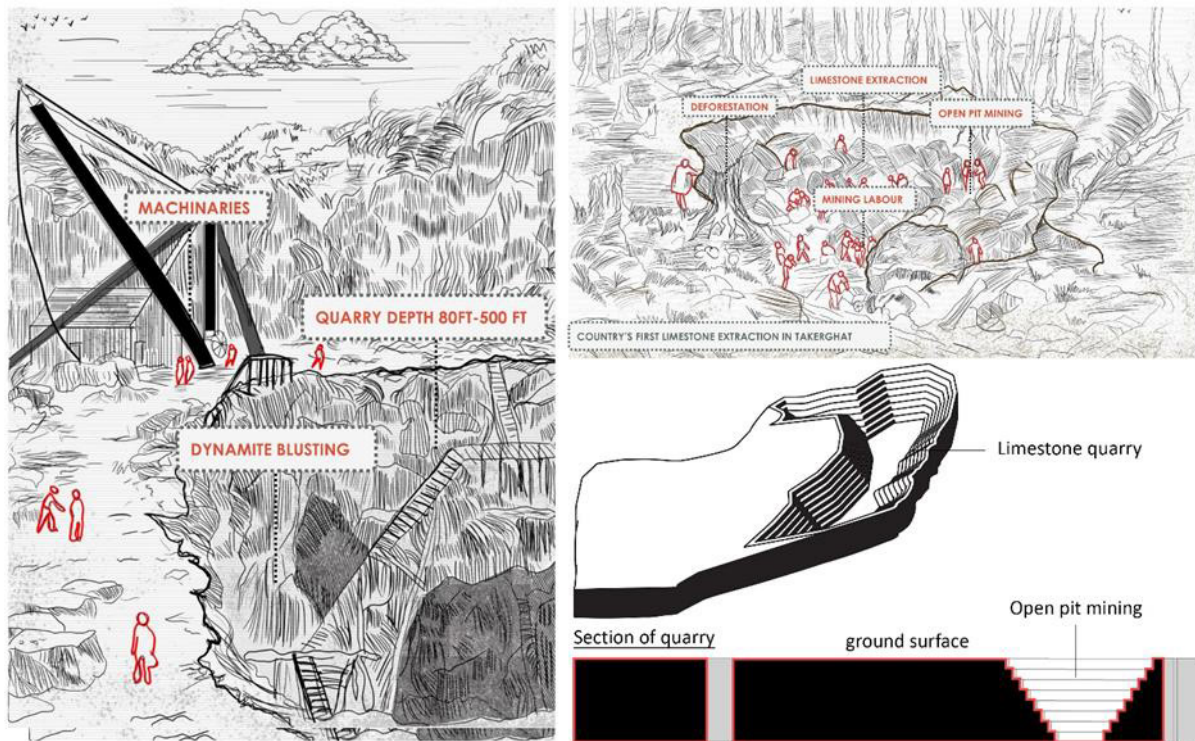


Figure 1. Limestone Mining Scenario in Takerghat Limestone Mining Project

After being processed, the limestone was transported by a rail track system from the quarry to the river. This approach efficiently carried vast amounts of material to the riverside. Once there, the limestone was loaded onto large boats that carried it along the river to the Chhatak Cement Factory. This logistical operation ensured a continuous supply of high-quality limestone for cement production, playing a crucial role in the regional economy and industrial growth. The entire process, from extraction to transportation, was designed to support the cement industry's demand while utilizing the region's natural resources. This methodical approach aided the local economy and established the groundwork for the Takerghat region of Bangladesh's historical and industrial significance.

2. LITERATURE REVIEW

2.1. Integration of the Tourism and Mining Industries

With the process of globalization, societal dynamics are adjusting to evolving social, economic, and global political standards. The tourism sector's market segmentation has greatly increased as a result of the broad acceptance of this strategy. To stand out and separate themselves, tourist locations have adjusted to match new global dynamics. They do this by embracing distinctive qualities and staying ahead of industry trends. The World Tourism Organization states that sustainable tourism must (a) make the best use of available natural resources, (b) respect the sociocultural identity of the area in which it occurs, and (c) benefit the people involved in its development both economically and socially [11]. Geotourism is a recently developed form of "environmentally innovative" tourism. It was once defined as just "geological tourism," but it has since been expanded to include travel that focuses on geology and landscape. It encourages the preservation of geodiversity, tourism to sites, and an understanding of earth sciences through education and enjoyment [12]. In addition to being an economic activity, mining also integrates and alters linked social and environmental sectors, transforming landscape parts and altering the environment, society, and natural resources along the route. At least 500 former mine exploitation sites have been transformed into museums,

parks, and other recreational spaces around Europe. Because of their historical significance, certain mining landscapes and the components that go along with them are regarded as belonging to the human legacy. A few historic mining sites from around the globe are listed on UNESCO's World Heritage List. The development of theme parks, geo-mining parks, geoparks, and other recreational and cultural attractions while maintaining a location's historical and geological identity and promoting an appreciation of both local culture and these features.

Landscape is viewed as a part of human heritage and culture. The cultural landscape, which blends indigenous natural elements with local traditions, has evolved through complex cultural, historical, social, and economic factors, all reflected within the natural environment [13]. According to Bridge (2004), "the mine sits at the nexus of history, politics, and culture, the focal point of a contested moral landscape" as a cultural landscape. One of the best examples of mining heritage tourist activities in Spain is the Riotinto district in southern Andalusia. These "revitalization" efforts, led by the Fundación Río Tinto, include the establishment of a mining museum, the restoration of a mining railway, the preservation of urban areas and archaeological sites, and the planning of guided tours of the mining district. [14]

2.2. Worldwide Initiatives to Rehabilitate Quarries

The ideas of mining tourism are currently being utilized for the mining heritage as a tourist attraction in many countries across the world. Rehabilitating quarries has gained global interest, with countries implementing innovative strategies to transform abandoned extraction sites into valuable ecological, cultural, and recreational spaces.

2.2.1. Tongluo Quarry Park: From an Abandoned Quarry to a Tourist Attraction

Tongluo Mountain in Chongqing, Southwest China, was once a hub for gravel mining due to its rich limestone deposits. There were hundreds of mining companies operating large-scale open-pit mining in the area in the 1990s. This intensive activity resulted in significant land damage, vegetation loss, and ecological degradation. Recognizing the environmental challenges and the urgent need for sustainable solutions, the quarry was officially closed between 2010 and 2012. The cessation of mining left behind 41 abandoned pits of varying sizes, posing substantial safety risks, worsening ecological conditions, and disrupting local livelihoods. The legacy of these activities highlighted the importance of balancing resource extraction with environmental preservation and community well-being.

Ecological Restoration Strategies

In Chongqing, Tongluo Mountain had a radical ecological restoration after intensive mining severely degraded it. Important problems like low water conservation, biodiversity loss, and poor rural landscape quality were found by a thorough survey. The local government responded by creating plans that prioritized ecological design, natural restoration, protection, and cooperative growth. Key initiatives included land greening, water restoration, and biodiversity conservation, integrated with rural revitalization and industrial development.

By promoting tourism and restoring the ecosystem, this all-encompassing strategy made Tongluo Mountain a prosperous tourist attraction. Sometimes referred to as the "green lung of the city and garden for residents," the area currently has recreational, medical, and rural tourist capabilities. The picturesque region has become extremely recognized, drawing over 20,000 tourists at peak periods and being dubbed the "Small Jiuzhaigou Valley of Chongqing," with its beneficial ecological and economic effects being widely praised [15].



Figure 2. Tongluo Mountain Recovery Journey from Abandoned Quarry to Tourist Attraction [15]

Improving the Ecology and Reestablishing the Natural System

Quarry Park serves as a cultural heritage site of the mining industry, embodying the concept of "natural healing and close-to-nature restoration." Restoring the site's ecological integrity is given top priority in the design, along with optimizing the social and economic advantages. It offers an example of sustainable development that incorporates principles that are centered on the environment, culture, and community to restore harmony between people, the land, and the surrounding environment. By the end of 2020, Tongluo Mountain Mine's ecological restoration endeavors had reached a 70% management and recovery rate. By establishing a flourishing ecosystem that drew animals like owls, pheasants, wild boars, and hares, this advancement greatly expanded the amount of forest cover and improved local biodiversity. The improved environment also uplifted the living conditions for over 720 villagers, contributing to a better quality of life and fostering a harmonious coexistence between nature and the community.

The ecological landscape of Tongluo Mountain has garnered significant acclaim from tourists since its trial operation in 2021. With daily peaks of 26,000 and an average of over 5,000 during holidays, the site has received 450,000 visitors. More than 200 residents have found work or founded businesses that provide services including dining cars, sightseeing buses, mini-trains, and mine items that are artistic and cultural. Tongluo Mountain hopes to earn a 5A rating as a national tourism destination, with an estimated 800,000 visitors each year. By combining ecological restoration with science promotion, education, culture, recreation, and wellness, it turns its "beautiful ecology" into a "beautiful economy."

2.2.2. Dalhalla: Sweden's Distinctive Outdoor Theatre Built in an Abandoned Quarry

Located in the tranquil landscape of central Sweden just north of Lake Siljan, Dalhalla stands as a one-of-a-kind venue. Once used as a limestone mining site, it has been transformed into one of Europe's most stunning outdoor theaters, known for its amazing acoustics, picturesque setting, and outstanding performances. The former Draggångarna quarry has become Dalhalla, a renowned cultural landmark that has transformed from an industrial site to a destination that attracts thousands of tourists with its unique atmosphere and wide range of artistic offerings.

Background and Transformation

Dalhalla is situated in Dalarna, a part of central Sweden renowned for its stunning scenery and historical importance, approximately 7 kilometers from Rättvik. The location was formerly a working limestone quarry, which was essential for the extraction of stone for building and other uses. The quarry, which was 400 meters long, 175 meters broad, and 60 meters deep, supplied a significant quantity of limestone until it was closed in 1990 [16]. The quarry, once called Draggångarna, has been restored into an amazing location. After more than half a century of blasting and excavation, Dalhalla's acoustically engineered arena was built with three-dimensional proportions that adhere to the golden ratio.

A Perfect Amphitheater in Nature with Outstanding Acoustics

The distinctive physical layout of Dalhalla creates a natural amphitheater that is perfect for outdoor events. Its stone walls naturally improve the sound quality, producing acoustics that are on par with the best outdoor stages in the world. Dalhalla's distinctive architecture guarantees crisp, clear sound, unlike conventional outdoor venues, making every performance special. Accommodating up to 4,000 spectators, the theater combines the quarry's rugged charm with modern amenities, offering a visually stunning and immersive setting. A varied program, including opera, classical music, jazz, rock, and pop events, is presented at Dalhalla every summer. World-renowned artists and ensembles, including the Bolshoi Theatre and Procol Harum, have performed here, drawing audiences from far and wide. Dalhalla presents a vibrant blend of musical genres and creative brilliance with 20 to 30 events every year [17]. Beyond just the shows, visiting Dalhalla is an experience. Setting the scene for the spectacular view of the quarry, the drive to the location winds through tranquil scenery. When music resonates off the rock walls and melds with the outside ambiance, especially at dusk, the scene is genuinely mesmerizing. Dalhalla exemplifies how a disused industrial site can transform into a cultural and natural harmony hub. It offers more than just performances; it delivers a memorable experience of music, art, and a specially revitalized environment.

3. METHODOLOGY

The initial phase of transforming the Takerghat limestone quarry into a tourism destination involves conducting a background survey and reviewing relevant literature to understand the current and historical conditions of the quarry and the surrounding area. This stage adopts a hybrid methodology, combining qualitative and quantitative approaches through a physical survey and interviews with local inhabitants and the mining community to get valuable insights into recent challenges. Additionally, data has been gathered from the Bangladesh Chemical Industries Corporation (BCIC) regarding mining activities, environmental effects, and community involvement, and also from the Geological Survey of Bangladesh (GSB) regarding geological factors.

Field Survey

Through the Field Survey, significant data on the site's current state and potential for growth as a tourist destination will be gathered. Important areas of attention consist of:

Geological Features: Identify significant geological formations, such as unique rock structures, mineral deposits, and fossil evidence that can be highlighted for educational purposes. These features also serve as a draw for tourists with an interest in natural history and geology.

Socioeconomic Conditions of the Mining Community: Evaluating the current socioeconomic status of the mining community is essential for assessing the impact of the tourism transformation. Many locals may rely on the quarry for their livelihoods, and any shift towards tourism must consider their role in the transition. The survey collects data on local employment, sources of income, and attitudes toward tourism in the neighborhood. This helps identify potential benefits, such as new jobs in tourism and hospitality, while also addressing concerns regarding the preservation of traditional mining practices.

Historical Significance: Documenting the historical and cultural significance of the quarry, especially its connection to the mining community, is crucial. The quarry's history, along with any folklore or local heritage tied to the site, will be recorded and integrated into the visitor experience. This helps ensure that the transformation respects and preserves the local culture, offering visitors a richer understanding of the area's past.

Questionnaire Survey

The transformation of the Takerghat limestone quarry into a tourism destination will involve a thorough engagement with the local mining community. Information will be obtained from people who work in mining as well as the larger local population via a questionnaire survey. The community's opinions about tourism development, its possible effects on local livelihoods, and their participation in associated activities will be major topics of focus. The survey will also explore concerns about preserving local culture and the social impact of tourism on traditional ways of life.

Mapping and Documentation

Mapping will play a crucial role in documenting the quarry's geological and infrastructural features, which are essential for planning tourism development. The following aspects will be mapped and documented:

Geological Mapping: Documenting the mineral deposits, structural features, and any significant geological formations such as chhora (water stream), and tilas (low hills) that could attract tourists.

Infrastructure Mapping: Recording the current infrastructure in the area, including roads, utilities, abandoned workshops, and buildings, to assess their potential for adaptation to tourism development.

Land Use Analysis: Determining current land uses in and around the quarry area will assist in identifying places that need to be maintained.

Precedent Study

Studying similar projects around the world provides valuable insights into successful approaches to transforming abandoned quarries into tourism destinations. It focuses on architectural best practices, sustainable interventions for tropical climates, and innovative uses of natural rock. The study highlights the work of renowned architects who have utilized natural rock formations to create functional and aesthetic designs, as well as adaptations for tropical climates to minimize environmental impact. Additionally, it explores how quarries have creatively integrated surrounding rock into both architectural features and environmentally sustainable practices.

Unveiling The Depths: Transforming An Abandoned Limestone Quarry Into A Tourism Destination in Takerghat, Sunamganj

4. RESULTS OF THE STUDY AREA

4.1. Site Location and Surrounding Area

The research area is situated in the Takerghat area of the Sunamganj District, close to the Indian border. It is located at 25°11'45.5"N latitude and 91°10'26.5"E longitude. Adjacent to Tanguar Haor and approximately 35 kilometers away from the district center, the Niladri Lake, which originated from an abandoned limestone quarry, is well-known for its clear blue waters and picturesque surroundings. Its closeness to India's Meghalaya Hills, which act as a natural border, offers a breathtaking backdrop of lush greenery and natural landscapes, boosting its potential as a major tourist destination for sustainable development.

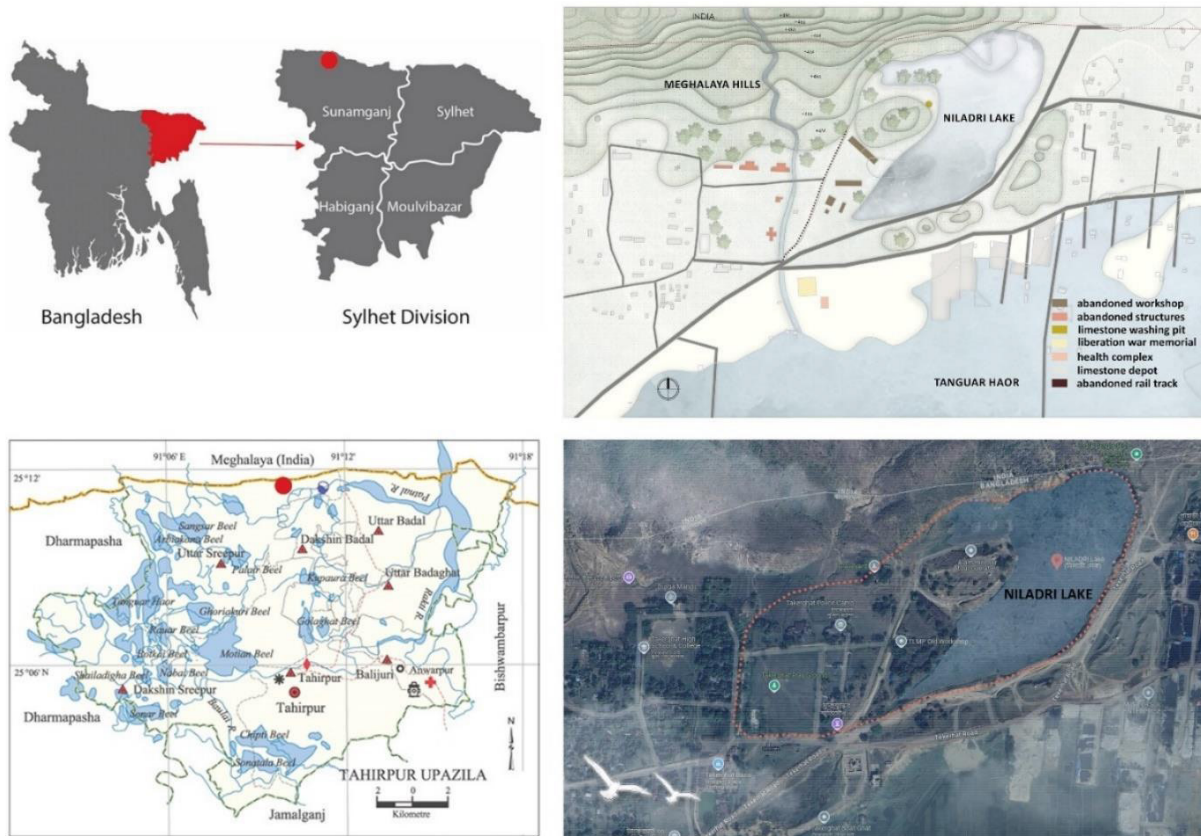


Figure 3. The Map shows the Geographic Position of Niladri Lake and the Adjacent Areas

The site surroundings of Niladri Lake vividly reflect its rich industrial history, intertwined with natural beauty. Among the remnants of its past are several abandoned machines that were once integral to the limestone mining operations. These machines, used for extracting and processing limestone, now stand as silent witnesses to the site's industrial heritage. Nearby workshops, where limestone was crushed into smaller pieces for industrial purposes, remain as physical markers of the site's former vibrancy. These structures served a vital role in preparing limestone for use in cement production and other industries. An old rail track that was originally used to load and transport limestone taken from the quarry adds to the area's historical value.

Additionally, a limestone washing pit can be found on-site that is involved in cleaning and preparing the raw limestone to meet industrial standards. Natural features like chora (streams) also run through the study area, adding to its ecological value and aesthetic appeal. Niladri Lake is a perfect location for investigating

sustainable tourism prospects while conserving its legacy because of the contrast between natural features and industrial remnants.



Figure 4. Scenic Landscape of Niladri Lake and Its Surrounding Environment

4.2. Site Evolution

The development of the site is a fascinating tale of natural recovery and industrial transformation. In the early British era, the region was first covered in dense trees, often referred to as "jungle." As time passed, human settlements began to establish themselves during the late British period, altering the natural landscape. In 1961, a geological survey led to the development of the Takerghat Limestone Mining Project. The subsequent quarrying activities reshaped the area, as limestone was extracted for various industrial uses, notably in cement production.

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Figure 5. Site Development and Landscape Changes Through Time

However, with the cessation of mining, the landscape began to evolve once again. The abandoned quarry was eventually filled with water by 1995, becoming Niladri Lake. This shift from an industrial site to a natural lake marked a significant change, creating a serene water body with clear blue waters surrounded by a rejuvenated ecological environment. Today, the site offers a balance of historical insights and scenic beauty, combining its industrial past with its growing tourism industry. The mine's depth varied from 80 to 500 feet, while Niladri Lake's depth is around 120 feet, reflecting the vast scale of the original quarry and its transformation into a tranquil lake.

The soil removed during limestone extraction was initially dumped in various areas surrounding the quarry. Over time, these piles of soil naturally formed low hills, contributing to the site's changing topography. These mounds not only reshaped the landscape but also enhanced the site's natural beauty. As the years passed, these artificial hills became integrated into the environment, adding to the scenic value of the area.



Figure 6. Evolution from the 1990 Takerghat Mining Operations (Photograph of Takerghat limestone quarry, ca. 1990, retrieved via Google; original source unknown) to the Current Natural Setting of Niladri Lake

The combination of the abandoned quarry, the newly formed hills, and the surrounding natural features now add a unique visual appeal, which could be a significant attraction for tourists visiting the area. This transformation highlights how industrial activities, while reshaping the land, can also create aesthetically pleasing features that blend with nature.

4.3. Tourist Attraction

The area surrounding Niladri Lake offers a diverse range of natural and cultural attractions, making it a significant destination for visitors. A major factor in attracting tourists to the area is Tanguar Haor, a wetland that is on the Ramsar list. Monsoon, Post-monsoon, and Winter are its three unique seasons, each of which adds to a dynamic environment that affects both local livelihoods and tourism-related activities. Several key attractions add to the appeal of the region. Takerghat Zero Point, located near the border, holds geographical significance, while Borochora and Barek Tila are known for their scenic landscapes. The Jadukata River has religious and cultural significance and is well-known for Pona Tirtho. Joynul Abedin Shimul Bagan, a striking forest of bombax trees, becomes particularly popular in spring when the trees bloom in vibrant red, creating a mesmerizing spectacle for visitors. The Meghalaya Hills' proximity to the location adds to its allure by offering a stunning backdrop of dense greenery and wilder landscapes. Additionally, from the study area, one can observe ongoing limestone extraction activities across the border in India, a reminder of the region's industrial past. Together, these elements contribute to the region's tourism potential, blending natural beauty, cultural heritage, and historical significance into a unique and evolving landscape.

Tourism in the Niladri Lake region has seen significant growth since it became widely recognized as a tourist destination in 2015. Currently, the site attracts approximately 500,000 visitors annually, solidifying its status as a prominent tourist hotspot. While the number of visitors fluctuates due to seasonal and external factors, the overall trend indicates increasing interest in the area. If a well-structured tourism development project is implemented, the growth rate of tourism is projected to rise by 2.5% annually from 2024 to 2034. This growth potential emphasizes how important it is to plan for sustainable tourism, develop infrastructure, and engage in conservation initiatives to guarantee long-term advantages for the environment and the local people.

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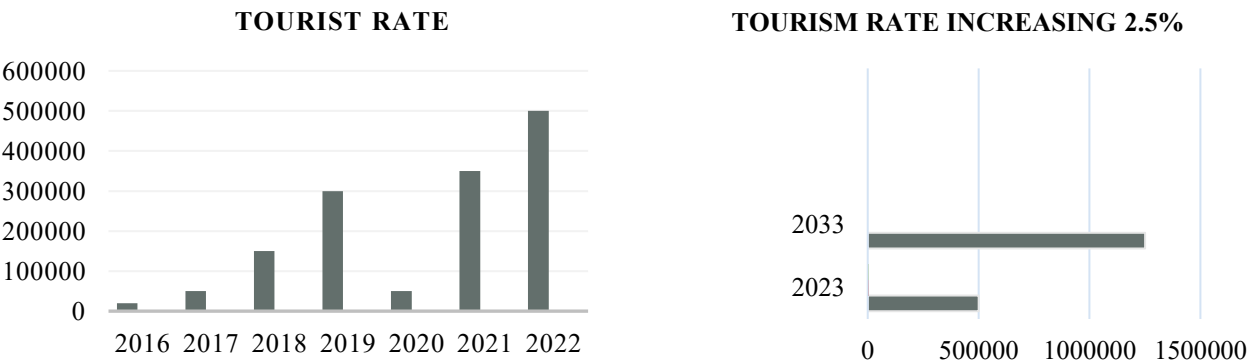


Figure 7. Increasing Trend in Tourism Rate Over Time

4.4. Miners' Present Situation in Takerghat

Since limestone mining in Takerghat has ceased, the local population, especially the former miners and their families, has faced serious socioeconomic difficulties. Many have been forced to look for other sources of income due to the financial uncertainty caused by the loss of mining jobs. Some have transitioned to agriculture, small-scale businesses, or eco-tourism activities like boating, while others work as loading or Barki laborers. However, the economic security that mining used to offer is often neglected by these replacements.

Currently, limestone is imported from India, and Barki laborers play a crucial role in loading and unloading the transported limestone. Although there are some job chances due to this physically demanding activity, wages are still poor and inconsistent. Migration has become a common strategy for survival, with many workers leaving for urban areas or other regions in search of better opportunities. Families rely on remittances from migrated members to sustain themselves, but this shift also brings social challenges, including family stress and potential community conflicts. Implementing skill development programs and financial diversification is essential for ensuring long-term stability. The difficulties faced by former miners and their families might be lessened by promoting ecotourism, enhancing regional infrastructure, and establishing long-term employment prospects.

4.5. Challenges and Obstacles to Tourist Development

Inadequate Tourism Infrastructure and Facilities: The tourism infrastructure in the Niladri Lake region remains underdeveloped, with limited accommodation, dining, and transportation options. A lack of funding and strategic planning has hampered the construction of the necessary infrastructure to properly host and serve tourists. As a result, tourists could discover that the location does not satisfy their basic comfort needs, lowering the quality of their trip.

Lack of Conservation Awareness: Both visitors and residents lack awareness of the significance of environmental preservation. This gap in awareness has resulted in environmental degradation, including pollution, unsustainable practices, and the neglect of natural resources. The absence of targeted conservation initiatives has further exacerbated the challenge, placing the area's ecological balance at risk. Again, most tourists are unaware of the historical significance of Niladri Lake due to the lack of information dissemination.

Limited Access to Pre-Travel and On-Site Information: The availability of reliable pre-travel and on-site information for tourists is inadequate. Promotional materials, maps, visitor guides, and signage that might help visitors navigate the area or learn about its attractions are noticeably inadequate. This absence

of accessible information discourages potential visitors and leaves many tourists unable to fully explore and enjoy the destination.

Limited Benefits for the Local Community: Tourism initiatives in the area have not sufficiently contributed to the economic and social well-being of the local community. A lack of opportunities for employment, entrepreneurship, or community-based tourism activities has resulted in limited community engagement and support. Because the local population isn't motivated to actively participate in or support tourism activities, the gap hinders the sustainable growth of the industry.

Scarcity of Food and Accommodation Options: The region provides limited options for food and lodging. Although houseboats provide some lodging and dining options, they are not enough to satisfy the wide range of guest tastes. Additionally, visitors looking for other lodging or food options have to make the trip to Sunamganj, which is inconvenient and detracts from the appeal of the destination.

5. DISCUSSION AND RECOMMENDATIONS

The study identifies two major challenges concerning tourism development at Niladri Lake: the lack of tourist facilities and the limited awareness of the site's rich history, particularly its connection to the Takerghat Limestone Mining Project. This research suggests developing a tourism destination that combines community involvement, historical preservation, and contemporary infrastructure to address these issues.

An experience center based on the concept of open-pit mining is a key component of the proposed hub. This center will preserve and narrate the history of Niladri Lake and the Takerghat limestone quarry, offering visitors an engaging and instructive experience. The architectural design of the center adopts a subterranean approach, blending seamlessly with the natural environment while reflecting the mining heritage of the area. This design ensures a harmonious balance between development and nature while respecting the ecological and aesthetic integrity of the site. To address the gap in tourist facilities, the hub would include diverse accommodation options, ranging from eco-friendly lodges to resorts, alongside restaurants offering local and international cuisine. These amenities are meant to make guests' stays enjoyable and unforgettable, which will encourage longer visits to the area. Recreational and educational features would also be integrated into the site, offering tourists opportunities to explore the quarry-like landscape, engage in leisure activities, and discover the history and natural beauty of the area. The landscaping of the site, which includes walking tracks, shady spots, and green spaces, is similarly important because it improves the hub's visual appeal and practicality. A dedicated parking facility will further improve accessibility and convenience for visitors, ensuring a seamless experience from arrival to departure. A significant aspect of the recommendation is the financial and social inclusion of the local mining community. By involving locals in the hub's operations, for example, through roles as guides, artisans, or service providers, the project will create sustainable livelihoods and cultivate a sense of ownership within the community. This involvement ensures that the economic benefits of tourism are shared fairly, strengthening community support for tourism initiatives and conservation efforts.

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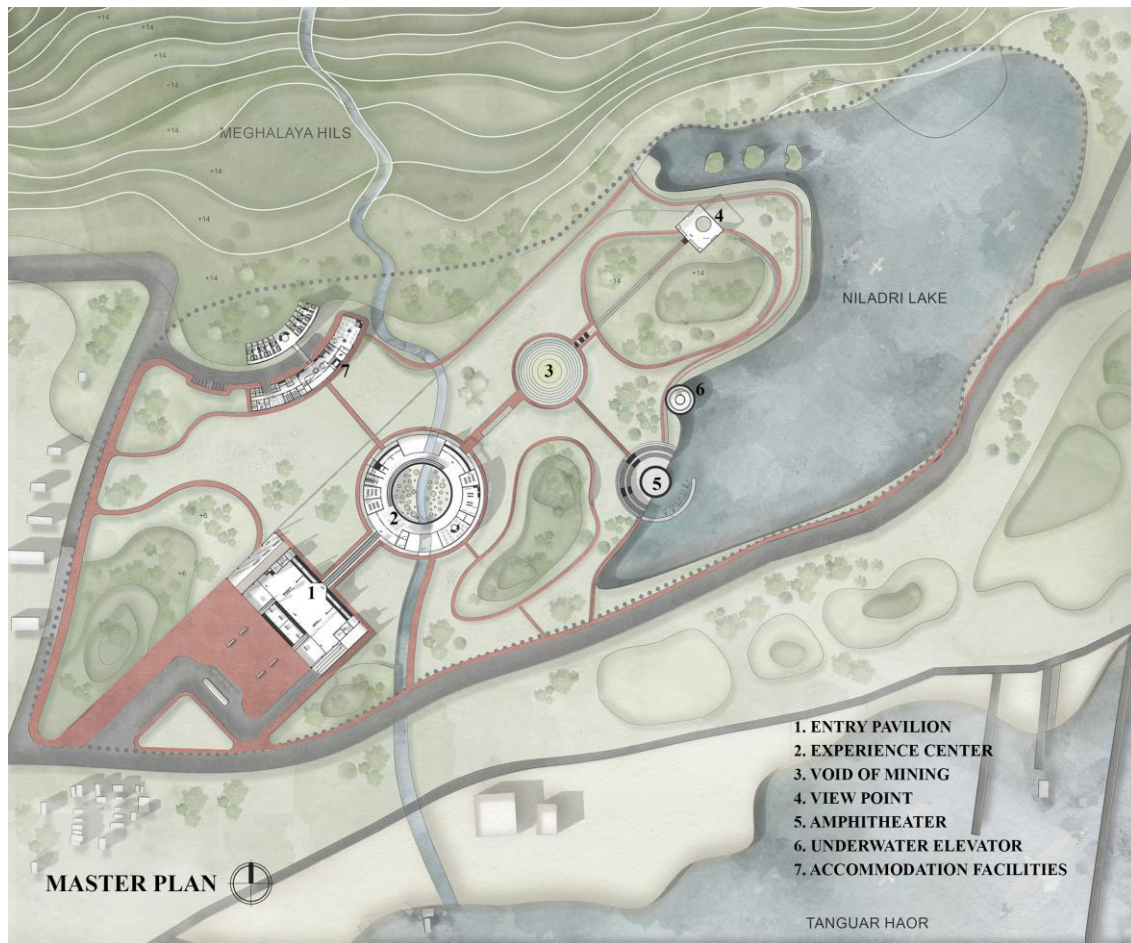


Figure 8. Masterplan Proposal for the Revitalization of the Study Area




6. CONCLUSION

This study has examined the transformation potential of the abandoned limestone quarry at Niladri Lake, demonstrating its viability as a sustainable tourism destination. Repurposing the quarry not only restores a once-degraded landscape but also promotes regional development and economic potential, according to the findings of thorough site analysis, historical research, and community participation. By integrating conservation strategies with responsible tourism practices, the site can serve as both a cultural landmark and an ecological asset. The integration of the site's historical and industrial heritage into tourism planning reinforces its cultural significance, allowing visitors to engage with its rich past while experiencing the natural beauty of the area.

Additionally, the proposed development, including an experience center, accommodation facilities, and recreational spaces, aligns with sustainable tourism principles. The project's master plan, which combines historical, educational, and recreational components, ensures visitors a comprehensive and engaging experience. The findings emphasize the need to balance tourism growth with conservation efforts. An increasing number of visitors may present challenges in resource management and environmental sustainability. Therefore, continuous monitoring and adaptive strategies are crucial to preserving ecological integrity while enhancing the visitor experience. Incorporating the mining community into tourism activities can also promote long-term financial stability and motivate them to actively protect the site's

historical significance. This approach creates opportunities for economic, social, and environmental benefits (Table 1).

Table 1. Development Opportunity Framework

Category	Opportunities
 Environmental	<ul style="list-style-type: none"> • Restores degraded land and quarry ecosystem • Encourages biodiversity and eco-awareness • Promotes sustainable land use
 Social	<ul style="list-style-type: none"> • Revives local culture and traditions • Engages the community in tourism roles • Improves local infrastructure and education
 Economic	<ul style="list-style-type: none"> • Creates alternative jobs for ex-miners • Boosts local businesses (food, crafts, lodging) • Attracts funding and investment

Ultimately, the transformation of Niladri Lake into a tourism hub exemplifies a forward-thinking approach to sustainable redevelopment. Through strategic planning and community-led projects, the location could develop into a major historical, cultural, and ecological attraction that will benefit locals and tourists for many years to come.

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Greening Strategies for Improving Existing Residential Buildings' Performance in Bahrain's Tropical Desert Climate



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Abstract: Bahrain's tropical desert climate significantly challenges existing buildings' energy efficiency and indoor comfort. The residential sector in Bahrain consumes up to 48% of national energy production. Cooling accounts for up to 80% of domestic energy use. Moreover, existing buildings require envelope renovation, and one of the least intrusive methods is greening strategies. The study's main objective is to assess the impact of retrofitting greening strategies on energy consumption and specify its optimum configuration. Simulations through DesignBuilder were conducted to model a typical housing unit in Bahrain. Results indicated that greening provides effective protection from solar radiation and reduces solar heat gains through building envelopes. Furthermore, the configuration of the green roof combined with the South and West green walls offered the best results in limiting indoor cooling energy demand. Findings suggest that retrofitting existing residential units could significantly reduce cooling loads and, therefore, reduce energy consumption.

Keywords: Building performance, Energy efficiency, Greening Strategies, Sustainable Building, Retrofitting.

Bahreyn'in Tropikal Çöl İkliminde Mevcut Konut Binalarının Performansını İyileştirmek İçin Yeşillendirme Stratejileri

Özet: Bahreyn'in tropikal çöl iklimi, mevcut binaların enerji verimliliğini ve iç mekan konforunu önemli ölçüde zorlamaktadır. Bahreyn'deki konut sektörü, ulusal enerji üretiminin %48'ine kadarını tüketmektedir. Soğutma, evsel enerji kullanımının %80'ine kadarını oluşturmaktadır. Ayrıca, mevcut binalar zarf yenilemesi gerektirmektedir ve en az müdahaleci yöntemlerden biri yeşillendirme stratejileridir. Çalışmanın temel amacı, yeşillendirme stratejilerinin enerji tüketimi üzerindeki etkisini değerlendirmek ve optimum yapılandırmasını belirlemektir. Bahreyn'deki tipik bir konut birimini modellemek için DesignBuilder aracılığıyla simülasyonlar yürütülmüştür. Sonuçlar, yeşillendirmenin güneş radyasyonuna karşı etkili koruma sağladığını ve bina zarfları yoluyla güneş ısı kazanımlarını azalttığını göstermiştir. Dahası, yeşil çatının Güney ve Batı yeşil duvarlarıyla birleştirilmesi, iç mekân soğutma enerjisi talebini sınırlamada en iyi sonuçları sunmuştur. Bulgular, mevcut konut birimlerinin yeniden donatılmasının soğutma yüklerini önemli ölçüde azaltabileceğini ve dolayısıyla enerji tüketimini azaltabileceğini göstermektedir.

Anahtar kelimeler: Bina performansı, Enerji verimliliği, Yeşillendirme stratejileri, Sürdürülebilir bina, Yenileme.

1.INTRODUCTION

Energy consumption for buildings has become more relevant due to the increase in population. With the increase of average temperature of about 1.1 °C, this could lead to increased cooling demand in buildings. The main driver for the increase in average air temperature is the rate of Green House Gas (GHG) Emissions, mainly CO₂ [1] the reliance on fossil fuels for energy generation is a main contributor to CO₂ emissions and therefore, emissions would be limited if energy generation is reduced. Currently, buildings consume up to 40% of total global energy generated, specifically in the MENA region where energy is generated from fossil fuels this leads to increased CO₂ Emissions. Moreover, several studies have noted that the average energy consumption in the MENA region is higher than average [2, 3, 4] or when compared with buildings in Europe. In the GCC region the demand for cooling load is the main contributor for elevated energy consumption [5]. This could be addressed by improving the efficiency of buildings but then even with reduced consumption relying on fossil fuel energy would still contribute to CO₂ Emissions and therefore energy generation should be implemented. Recently, Net Zero Energy Buildings has been gaining interest in literature and seems like a strategy that might improve both building efficiency and buildings' reliance on fossil fuels for energy [3, 4, 6].

Passive Strategies

Buildings' envelope determines the ability or the extent to which a building is able to resist the harsh atmosphere conditions surrounding it without requiring any energy or mechanical instruments. for example [3] discusses the potential for NZEB and near Zero Energy Buildings (nZEB) in the MENA region and discovered that the regulations and standards for buildings require an overhaul in order to improve the buildings' efficiency, for example air infiltration rates should be limited to 1.2ACH, walls should have a U-value of 0.17 W/m².C to reach nZEB standard. Moreover, building envelope resistance to heat exchange (U-value) is a main factor in its efficiency and therefore should be carefully considered. The building envelope includes Walls, Roofs and Windows. The efficiency of the materials is measured by their rate of heat exchange (U-value) [7], [8]. In a recent study in Riyadh, KSA, [4] studied an existing 3 story 597m² residential unit and found that walls have a U-value of 0.8 W/m².K, Windows have a U-value of 1.7 W/m².K with window to wall ratio (WWR) of 5% and roof and were able to achieve net zero energy through changing the HVAC system and relying on solar power generation. On the other hand, [3] discovered that walls and roofs would require a minimum U-value of 0.17 W/m².C and 0.11 W/m².C for a building to reach the status of a near Zero Energy Building (nZEB). In addition to construction materials, other methods can be employed to improve the passive abilities of buildings, for example through increasing the albedo, i.e the solar reflection of the buildings' exterior. This can be achieved through using cool materials, green walls, green roofs or even utilising shading [9]. Moreover, cool materials offer a reflectivity of 50% or higher, allowing for lower absorption of solar energy, in comparison to typical building materials might have a reflectivity of 5%, introducing cool materials could reduce surface temperatures by 10°C [10]. Green walls and roofs also serve as a great solution for passive insulation, when compared to typical roofs covered with bitumen and have a potential to reduce solar energy absorption due to its high reflectivity 70-85%[11], however, green roofs and walls should be carefully planned and studied to ensure its effective with present climate, [12] demonstrated that green roofs and walls effectiveness is more significant in hot and dry conditions. Another study displayed high potential using green walls with reductions in heat gains up to 97% (west orientation) and a reduction in heat loss about 30% [13]. However, greening for both walls and roofs has shown an increase of relative humidity for both indoors and outdoors, [14] investigated the impacts of green walls in a tropical climate setting and discovered that even though it resulted in a reduction in the air and surface temperatures, the green wall caused an elevation in indoor humidity by approx. 43%. On the contrary, in Daemei's experiment [15], they tested a green wall and measured data for both indoors and outdoors, while outdoors experienced an incremental increase in relative humidity, the indoors experience a 32% reduction in relative humidity. This most likely means that the results could depend on the climate of the location. Although passive strategies massively improve buildings' abilities to withstand

weather conditions, indoor climate systems are essential for creating a pleasant environment for residents and users, that is why mechanical cooling/heating is important for every building since around 60-70% of building energy [5] consumption goes for HVAC, mainly efficient systems are able to provide a higher output compared to its energy input.

Active Strategies

Maintaining a pleasant indoor environment is essential and therefore, heating, air ventilation and conditioning (HVAC) is utilised. In colder climates heating is the main requirement for pleasant indoors while in warmer climates cooling through air conditioning is provided. The term active strategies are quite broad and include numerous mechanical systems and instruments and since the focus here is on the GCC region, only cooling systems will be discussed in this review. Several studies explored the potential colling instrument appropriate in terms of efficiency in the GCC region, [4] compared a ground heat pump (GHP) to a one package HVAC system and found that even though a GHP costs twice as much it offers savings up to 52% in input power. Also, the GHP shows potential in reducing CO₂ emissions to about half, reducing noise, it seems the only downside is the initial cost of the system. Moreover, other systems were explored by [3] for MENA region and concluded that a Heat Pump System. Split Air Conditioning and High Package Terminal Acs all pose as a potential solution towards NZEB and nZEB buildings.

Energy Generation

In the kingdom of Bahrain, Photovoltaics (PV) are the best option due to the abundance of solar radiation. Moreover, other methods such as wind turbines were considered, but are not fully feasible in Bahrain due to low wind speeds, vibrations generated on site [16]. Moreover, PV panels with a size of 7.8kW would be feasible and can produce up to 12,500 kWh annually [17]. Lastly, other literature also tested the potential of the T8 unit for solar power generation and also concluded that covering the roof of the residential unit would produce up to 12,500kWh per year [18].

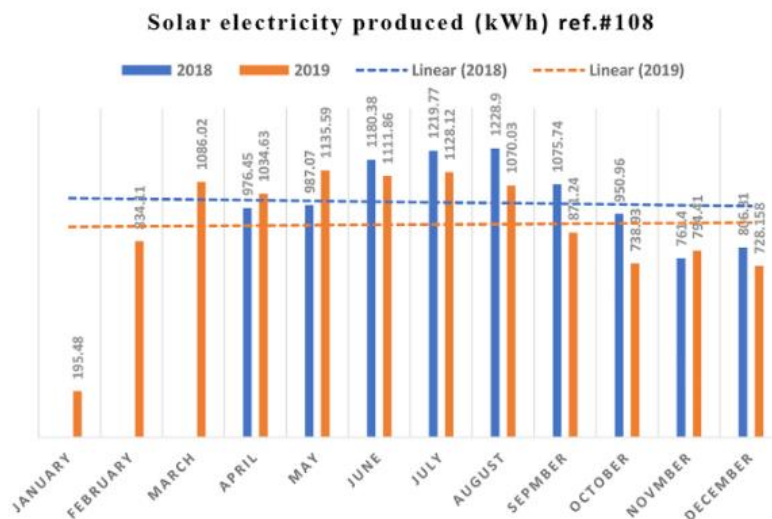


Figure 1. Energy Generation for two years of a 7.8kW solar PV system in Bahrain [17]

Energy Consumption

Currently about 50% of the total global population are living in urban areas and this is projected to increase in 2050 to 68%, the increase in population also leads to an increased demand for energy and more specifically in economies relying on fossil fuels this also leads to elevated GHG emissions [19]. Moreover, oil and gas account for 80% in terms of energy generation further increasing the need for alternatives [20].

Greening Strategies for Improving Existing Residential Buildings' Performance in Bahrain's Tropical Desert Climate

The residential and commercial sectors, both account for 50 – 65% of total energy consumption globally while also contributing to about 60% of CO₂ emissions [21] and from the global GHG emissions this accounted for 28%, almost a third of global emissions from other sectors such as industry, transport and construction [22]. Furthermore, [3] estimated the normalized residential building consumption and found that in Bahrain a residential building would require 281 kWh/m² annually and this is considered high when compared to the Association of Heating, Ventilation and Refrigeration Engineers (ASHRAE) 90.1 code for efficient energy which for Bahrain would be 87 kWh/m² annually. On the other hand, in another study it was found that residential units in the kingdom of Bahrain reach an annual normalized consumption between 70-85 kWh/m² [5], this could indicate that some data available may not be very accurate and requires more investigation. Moreover, in Europe, countries introduced targets in order to limit energy consumption for example, Spain with 120 kWh/m² annually, Romania 120-140 kWh/m² annually with the intent to even reduce these values more in the future for nZEB implementation [23].

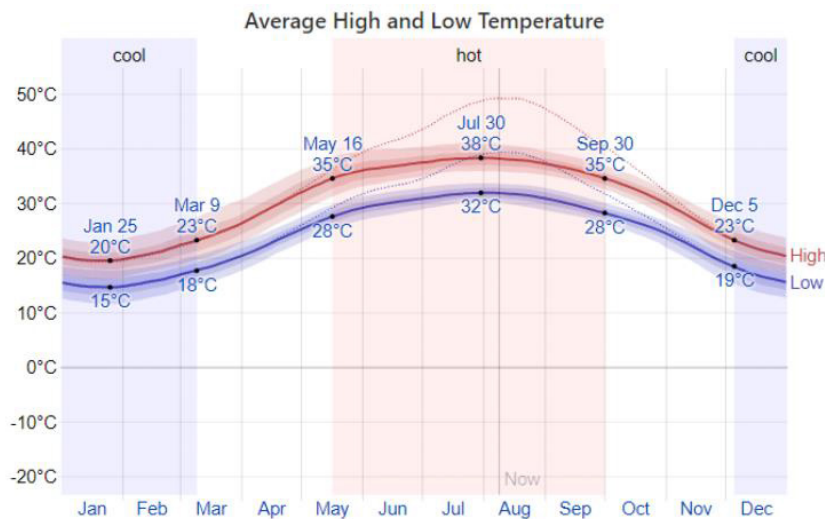


Figure 2. Bahrain annual weather [26]

Bahrain Climate

The Kingdom of Bahrain is an archipelago of 51 natural islands and 33 artificial islands, with Bahrain being the largest island, the total area of the kingdom is 780 km² [24]. The Kingdom of Bahrain is situated near the east coast of the Kingdom of Saudi Arabia between a Latitude and longitude of 25° 30' 26° 20' N and 50° 20' – 50° 50' E, respectively. On average the warm season lasts for 4.5 months from the month of May to September with the average high temperature reaching 35°C and average low being 32°C. The cool season only lasts for 3 months with an average daily high under 23°C. Rainfall is often recorded to occur between October and April with most of the rainy days taking place during January with a high rainfall average of 11mm. Humidity levels are high on average with the muggier period lasting up to 7.5 months, from April to November reaching above 75% on some days during August [25]. The warmest month during the year is July, with the average high being 38°C and average low at 32°C [26].

Energy Consumption in Bahrain

For the case of the Kingdom of Bahrain, most of the energy is consumed by the residential sector, according to the pie chart below (Figure 3) [27], 48% of total energy consumption in the Kingdom, including the industrial sector [28]. These numbers are also supported by the annual Electricity and Water Authority (EWA) report, with the latest consumption by sector indicates that domestic consumption in 2022 accounted for 8,733 GWh out of total consumption by all sectors of 18,293 GWh which equals 47.7% (Figure 4), [29]. Furthermore, Energy consumption in the residential sector is mainly the result of high

cooling demand, with cooling degree days (CDD) value of between 3,200 – 3,600°C annually [5],[27]. This indicates that cooling is essential, and therefore a considerable portion of domestic energy consumption could be attributed to cooling demand. Moreover, in two studies it was found that the cooling demand and reliance on air conditioning for residential buildings in Bahrain accounted between 71-80% of total energy consumption [27], [5], both simulations and collected energy bills has shown very similar data, more importantly the peak in energy demand is reached during the summer season which further indicates that cooling is main the contributor to high energy consumption. Figure 4 below shows consumption by sector has increased by 6.5% between 2018 and 2022 1.8% annually.

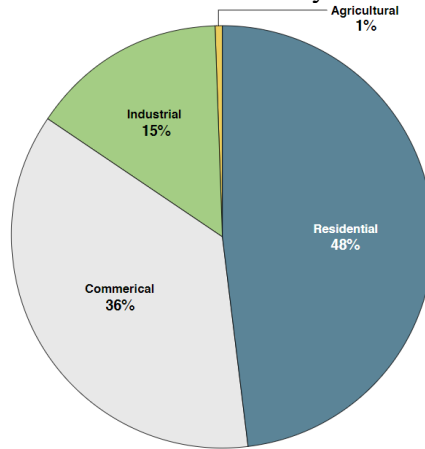


Figure 3. Energy consumption of different sectors in Bahrain [27]

Net Zero Energy Buildings (NZEB)

According to [30] net zero energy is achieved by reaching the highest energy efficiency via implanting renewable energy generation on site. Therefore, this process is done on two levels, first, through the reduction of energy consumption (passive strategies) and second by offsetting the energy consumed through site generated energy (active strategies). Moreover, NZEB encapsulates many challenges that have to be addressed in order to achieve the desired outcome, first, the building envelope, second, indoor climate control systems for cooling and heating (HVAC), third, energy generation systems, and fourth, automation systems for buildings [31]. Furthermore, NZEB is beneficial on three main levels, economic, environmental and social. Economically, it can offer better efficiency and therefore offer savings in energy consumption, reduce maintenance costs due to high efficiency and offer better resale value due to the aforementioned benefits [32]. Environmentally, NZE buildings offer superior insulation and air tightness, better indoor air quality and improved heat gain/loss and a reduced carbon footprint by reducing its loads and therefore reduces its reliance on fossil fuel generated electricity [33]. Lastly, on a social level, NZEB has potential to involve residents in the decision-making process and have the residents completely aware of the maintenance process [34]. Potentially, NZEB buildings could pose as a solution for energy consumption, however, it is important to optimize buildings' performance through passive strategies as much as possible and therefore such strategies should be studied. Achieving NZE for residential buildings in the region has been shown to be feasible [4]. However, the suggested values for walls and roofs in the studies do not seem to be feasible or might prove to be very expensive to implement, currently, the Kingdom of Bahrain regulations suggest walls and roofs to have a U-value of 0.57 W/m²C and 0.3 W/m²C. Furthermore, the energy generation seems to be much more feasible with estimated generation of 12,500 kWh for a single story house in Bahrain. This review aims to shed light on the potential of NZEB buildings in Bahrain of which data shows it can pose as an effective strategy in limiting the domestic energy consumption while achieving to reach Bahrain's 2060 carbon neutrality goals [2]. According to reviewed literature, many factors dictate the efficiency of building performance, more specifically the potential of greening strategies

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in reducing cooling demand in the region is limited but shows a lot of promise in other international studies. In theory green walls and roofs might greatly reduce solar loads on building envelopes while offering a cost effective solution for new and existing buildings [35]. points out that energy retrofitting existing buildings could be the best approach in reducing energy consumption.

المجموع Total	زراعي Agricultural	صناعي Industrial	تجاري Commercial	منزلي Domestic	السنة Year
17,321	62	2,786	6,307	8,166	2018
17,027	60	2,769	6,515	7,683	2019
16,520	74	2,354	5,631	8,461	2020
18,019	64	2,891	6,487	8,577	2021
18,293	56	2,919	6,585	8,733	2022

Figure 4. Annual Energy Consumption report from 2018 - 2022 [29]



Figure 5. Requirements for NZEB Residential Building [6]

2.METHOD

2.1. Study Design and Setting

For this study, a typical residential unit called the T8 unit was selected. The unit selected for the study is a typical housing unit offered the Ministry of Housing in the Kingdom of Bahrain, called the T8 Unit. This unit has been used in various residential cities such as Arad, AlBusaiteen, Askar, AlBurhama, West Riffa and 9 more cities. This residential unit was designed to house a family of 5 members. The villa's area is 209m² and includes two living rooms, kitchen, 3 bedrooms and 4 bathrooms [36]. Such residential units finished in 2015, follows thermal insulation regulations pre 2019, which states that maximum allowed u-values for walls and roofs are 0.75 and 0.6 W/m²C, respectively. These values concerning the building envelope directly impacts cooling demand of indoor spaces and therefore amending the envelope with greening strategies might offer benefits for reducing cooling demand of existing buildings in the Kingdom of Bahrain. A common method for studying buildings' performance is through running computer simulations on a 3D model of said building. Through the reviewed literature, methods were summarized along with applicable parameters from each software. Moreover, Designbuilder was selected mainly for its

reliance on EnergyPlus calculations and high level of detail when it comes to modifying material properties, occupancy schedules, HVAC systems efficiency, lighting loads and more. Table 1 below shows a summary of similar studies methods. The building digital 3D model will be created based on the provided technical plans. Then, the building envelope material properties are entered into the simulation in addition to the weather data file for the climate. Data for power generation for the same model is gathered and validated from available literature. The simulation will be broken into two phases. First phase will provide information regarding the typical housing unit (T8) and establish a base line for the comparative analysis. The second phase will include several simulations for different configurations of green strategies for walls. Finally, data is comparatively analysed to evaluate the benefits of green walls. Below (Figure 6) is an illustration for the process and integration of data. Regarding energy consumption, a schedule was placed for the occupancy of the residential unit. Specific times for sleeping, using the living room and kitchen. It is worth noting that many appliances were not accounted for and the schedule proposed is based on personal experiences with family life in the Kingdom of Bahrain. moreover, the proposed schedule took into account workdays and weekends, for example, accounting for extra sleep hours, late hours in the living rooms or additional hours for the majlis where family visit occur during weekends. These schedules are essential in terms of determining cooling demand, since every occupied space is air conditioned except for Bathrooms. HVAC in the residential unit is present in the form of Split Air Conditioning units, installed wherever needed (Bedrooms, Living rooms and Kitchen). For this model, the efficiency of Acs was considered, based on the year the units were built Electricity and Water Authority (EWA) had not enforced any regulations in terms of power consumption. Therefore, the coefficient of performance (COP) for the units were kept as default in the software at 1.8. It is worth noting that COP of split air conditioning units are available in the kingdom with a higher COP after enforcing new laws in 2017 [37]. Greening solutions offer the ability to cover existing structures and according to available literature provides protection against solar radiation and heat, specifically in regions with high global solar radiation due to its shading ability and evapotranspiration [38], [39]. Due to the limited time to conduct this study, the best performing solutions from available literature were selected for this study. It was decided to select an extensive green roof system and for walls a modular green wall system due to its ability to be applied on top of the outer layer of the walls and high insulation properties [40], [41]. Table 2 in the next page summarizes each configuration with corresponding model properties. Baseline is a typical residential unit without any alterations, while others will have some level of treatment either for roof only, walls only, or both walls and roofs.

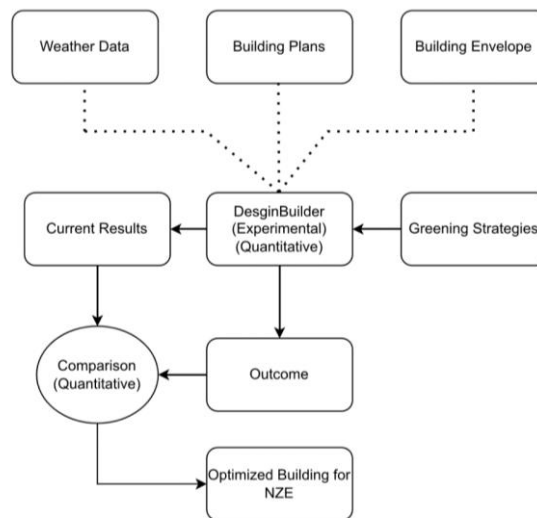


Figure 6. Simulation process for the T8 unit.

Table 1. Analysis of Methods, tools and outcomes for the reviewed literature.

Author	Method	Tool	Parameters	Outcome	Research Methodology
(Al-Saeed and Ahmed, 2018)	Simulation	<ul style="list-style-type: none"> •BIM Revit via Insight 360 	<ul style="list-style-type: none"> •Building Envelope •WWR •Window type •Potential PV gen •HVAC System & Operation •Appliance Efficiency •Air Infiltration 	<ul style="list-style-type: none"> •Guidelines for future regulations and values for insulation based on normalized consumption 	<ul style="list-style-type: none"> •Experimental •Quantitative
(Ismaeil and Sobaih, 2023)	Simulation	<ul style="list-style-type: none"> •Hourly Analysis Program (HAP) Pvsyst V7.1.0 Software 	<ul style="list-style-type: none"> •Building Envelope •WWR •Window type •Potential PV gen •HVAC System & Operation for a GHP system. •Appliance Efficiency •Air Infiltration 	<ul style="list-style-type: none"> •Guidelines for installing dual renewable energy systems (GHP and PV) for residential units in KSA. 	<ul style="list-style-type: none"> •Experimental •Quantitative
(Daamei, et al., 2021)	Field Measurement Simulation	<ul style="list-style-type: none"> •EnergyPlus •Artificial Neural Network •Envi-met •Data Logger 	<ul style="list-style-type: none"> •Outdoor Air Temperature for green and non-green walls •Indoor Air Temperature for green and non-green walls •Indoor Relative Humidity •Outdoor Relative Humidity 	<ul style="list-style-type: none"> •Established a predictive model for predicting air temperature around the green wall and validated it. 	<ul style="list-style-type: none"> •Empirical •Quantitative
(Ratih, et al., 2018)	Miniature Model Field Measurement	<ul style="list-style-type: none"> •Hygrothermo meter (AT, RH) •IR Surface Thermometer. •Environment Tester for Windspeed. 	<ul style="list-style-type: none"> •Surface Temperature (Indoor & Outdoor) •Air Temperature (Indoor & Outdoor) •Relative Humidity (Indoor & Outdoor) •Wind Speed. 	<ul style="list-style-type: none"> •Established the impact of a green system in terms of air temperature, surface temperature and relative humidity in a tropical climate. 	<ul style="list-style-type: none"> •Experimental Quantitative

Table 2. Different configurations for the simulation of green strategies.

Configuration	Walls	Treatment	Roof	Treatment
Baseline	Typical Concrete Wall Sandwich 0.75W/m ² C	Non	Typical Concrete with Insulation + Water Proofing 0.6W/m ² C	None
R	Typical Concrete Wall Sandwich 0.75W/m ² C	Non	Typical Concrete with Insulation + Water Proofing 0.6W/m ² C	Extensive Green Roof 0.57 W/m ² C
WR	Typical Concrete Wall Sandwich 0.75W/m ² C	Modular Green Wall 0.4W/m ² C	Typical Concrete with Insulation + Water Proofing 0.6W/m ² C	Extensive Green Roof 0.57 W/m ² C
SR	Typical Concrete Wall Sandwich 0.75W/m ² C	Modular Green Wall 0.4W/m ² C	Typical Concrete with Insulation + Water Proofing 0.6W/m ² C	Extensive Green Roof 0.57 W/m ² C
SWR	Typical Concrete Wall Sandwich 0.75W/m ² C	Modular Green Wall 0.4W/m ² C	Typical Concrete with Insulation + Water Proofing 0.6W/m ² C	Extensive Green Roof 0.57 W/m ² C
NESWR	Typical Concrete Wall Sandwich 0.75W/m ² C	Modular Green Wall 0.4W/m ² C	Typical Concrete with Insulation + Water Proofing 0.6W/m ² C	Extensive Green Roof 0.57 W/m ² C
NESW	Typical Concrete Wall Sandwich 0.75W/m ² C	Modular Green Wall 0.4W/m ² C	Typical Concrete with Insulation + Water Proofing 0.6W/m ² C	None

3.RESULTS & DISCUSSION

Results show that the configuration for greening strategies directly affected its efficiency in reducing the cooling demand. Interestingly, reductions in cooling demand are more noticeable during the summer season. The graph in figure 8 illustrates changes in cooling energy demand of the different scenarios. In the “Roof Only” configuration, cooling demand is almost identical for cool months (Oct-Apr), however, during the summer changes become more apparent but are still negligible with a reduction in cooling demand approximately 0.4%. Moving on, it is obvious that coupling roof and walls yields better results in terms of cooling demand reduction. Even by only combining greening strategies for the roof and the west wall resulted in an 11% reduction in annual cooling demand. Moreover, covering the south wall resulted in even more reductions in cooling demand, up to 14%. Lastly, combining roof with south and west wall resulted in the highest reduction in annual cooling demand with 23% less energy for cooling when compared to the baseline and 10% when compared to roof and south wall configuration.

Furthermore, it seems that the impact of green strategies is amplified during the summer months, table 3 below shows the monthly change in cooling demand for all configurations compared to baseline. The warmest months of the year experience the most reductions. However, during the winter months, the simulation shows negative values, indicating that the models required slightly more cooling (2 to 13%) compared to less insulated configurations. Usually, simulation tends to slightly overestimate cooling for winter months and underestimate cooling in summer which could also indicate higher reductions in a real scenario.

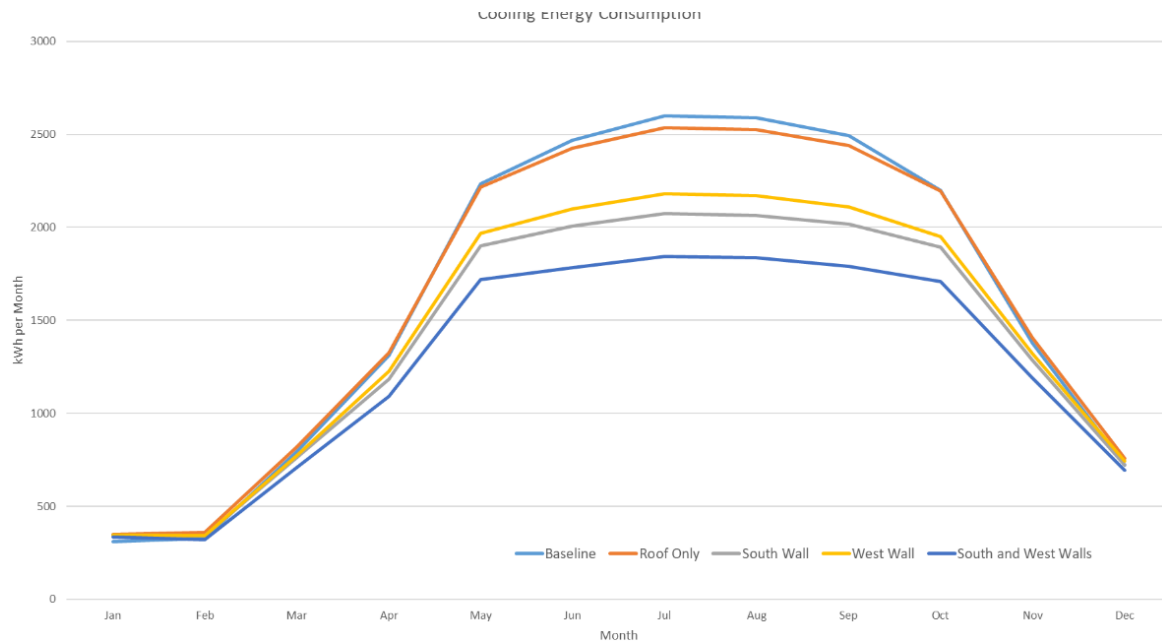


Figure 7. Changes in cooling consumption based on configuration.

The strength of green strategies be it for roofs, walls or both, is that they can be retrofitted onto existing buildings' envelopes. Building envelope is the protective shell separating indoor environment from outdoor climate conditions. Furthermore, greening could be a solution for future improvement of existing buildings, with the goal being reduction in cooling loads. Results have shown that an extensive green roof coupled with a modular green wall covering two orientations could result in 24% savings in terms of cooling energy demand. On the other hand, it must be mentioned that green roof solution may not be the best solution for retrofitting the roof area. Currently, thermal insulation regulations for building roofs in Bahrain require a maximum u-value of $0.3 \text{ W/m}^2\cdot\text{C}$, which is much lower than an extensive green roof and should be explored as an option for future studies. Furthermore, for this case, reflective and shading strategies could potentially be more beneficial in terms of roof area, keeping the roof accessible also reserves the potential for future solar PV installation. This aspect should be studied to find the optimal configuration of insulation and green strategies for retrofitting. Also, in terms of greening, numerous benefits were not covered in this study, such as carbon sequestration, contribution to air quality, ability for shading and maintenance could be further explored. Additionally, some literature is available for utilizing artificial green strategies in order to avoid maintenance requirements, but this also nullifies any other environmental benefits [42].

Table 3. Monthly cooling demand for every configuration.

	Config.	Change in cooling load for every configuration compared to Baseline							
Month	Baseline		Change%	West Wall kWh	Change%	South Wall	Change%	S&W walls	Change %
kWh	Roof		-13%	344.6456	-12%	345.4182	-12%	335.2085	-9%
kWh	Change%	West Wall	-9%	343.4102	-5%	342.3937	-4%	321.0647	2%
kWh	Change%	South Wall	-3%	772.5141	2%	759.1381	4%	707.9501	11%
Jan	308.2658	349.3409	-1%	1224.585	7%	1184.047	10%	1089.224	17%
Feb	328.2057	358.0864	1%	1966.207	12%	1900.37	15%	1719.745	23%
Mar	791.7454	816.4457	2%	2099.537	15%	2005.939	19%	1782.684	28%
Apr	1310.964	1325.004	2%	2180.836	16%	2073.912	20%	1842.484	29%
May	2234.2	2217.535	2%	2171.425	16%	2063.946	20%	1836.73	29%
Jun	2469.649	2425.133	2%	2110.92	15%	2017.467	19%	1789.36	28%
Jul	2600.515	2537.225	0%	1950.122	11%	1891.472	14%	1707.606	22%
Aug	2588.301	2525.85	-2%	1320.376	4%	1287.931	7%	1190.556	14%
Sep	2492.507	2441.63	-5%	741.866	-3%	720.5879	0%	692.3079	4%

Moreover, Configuration SWR shows the best promise offering only three surfaces to be covered while showing low cooling demand relatively. For example, when all walls are treated except for the roof, cooling demand increased by only 9% compared to SWR. Consequently, treating all walls and roof only reduced cooling loads by an additional 1.7% compared to SWR configuration. Figure 8 above illustrates cooling energy consumption for different configurations. Moving on, greening strategies proposed in this study have shown potential for reducing cooling loads. The goal of this study was to evaluate the ability of such strategies in assisting existing residential buildings achieve NZE or nZE. Solar PV system for a similar unit would generate up to 12,500 kWh annually, when this is compared to the best configuration (SWR), solar energy generated annually could cover up to 83% of annual cooling energy demand and 66% of total energy demand. It is worth noting that the model included did not account for retrofitting lighting and new efficient cooling systems, further improving the building cooling system efficiency could immensely reduce energy consumption, it will be definitely explored in the future [39].

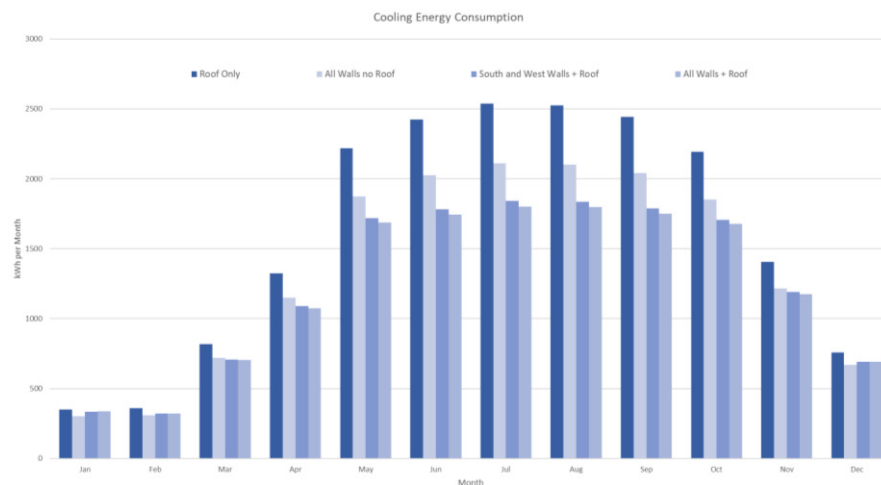


Figure 8. Comparison between monthly cooling energy consumption for worst and best performing configurations.

Table 4. percentage of total energy consumption covered by solar energy generated for every configuration.

Configuration	Annual Cooling Energy kWh	Change %	Generated Power kWh	Energy Offset kWh	Renewable Energy %
Baseline	19422	-	12,500	6922	44.6%
W	19353	0.36%	12,500	6853	45.2%
WR	17226	11.3%	12,500	4726	62.2%
SR	16593	14.6%	12,500	4093	67.3%
SWR	15015	22.7%	12,500	2515	79.9%
NESWR	14759	24.0%	12,500	2259	81.9%
NESW	16368	15.7%	12,500	3868	69.1%

5.CONCLUSION

This study explored the potential for retrofitting green strategies for Bahrain's tropical desert climate, it can be concluded from this study that coupling roof and wall strategies yields better results, specifically when focusing on south and west facades. The study found that when green roofs are coupled with green walls offer benefits in terms of reducing building cooling loads up to 23% which is aligned with findings from similar literature [43]. Such reductions in terms of cooling could prove beneficial in the future for reducing carbon emissions and transitioning into nZE buildings but greening strategies alone does not seem to be sufficient, treatment of other envelope elements like windows and AC systems could elevate the benefits of retrofitting green strategies. On the other hand, maintenance, plant species and environmental impact of greening strategies must be studied for the context of Bahrain, more specifically its impact on outdoor and indoor humidity level. Besides, this study has faced several limitations, such as time frame for running simulations and tests was not sufficient and this study will pose as preliminary research with the ultimate goal being finding the optimum configuration for greening strategies for the Kingdom of Bahrain. Also, this study covered one type of residential unit and more should be explored in the future. Going on, after this study, more comprehensive solutions would be studied, potential of reflective insulation and shading would be explored alongside green strategies.

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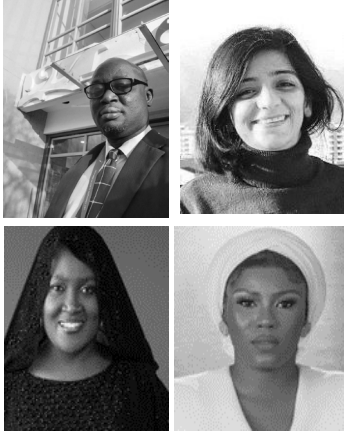
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Assessment Of Housing Condition And Maintenance Practice In Nigeria University Staff Quarters: A Case Study Of University Of Ilorin



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Abstract: The Provision of staff housing, particularly in Nigeria's tertiary institutions of learning, is becoming unrealistic, a need for efficient maintenance of existing housing. This study investigates the condition of housing and maintenance practices in staff housing. The research utilized both primary and secondary sources of information collected from staff in the University of Ilorin quarters with a questionnaire; 117 samples out of 234 sample frames were randomly selected. Primary data, such as residents' socio-cultural, housing typology, facilities condition, and maintenance procedure, were collected. It made use of the Statistical Package for Social Sciences (SPSS) for the analysis, while frequency count, percentages, and tables were utilized in the findings' presentation. The study revealed that 53%, 43.6% of foundations, floor respectively is in good condition, while 47.7% of walls are in poor condition, 40.2%, 29.1% show dissatisfaction, satisfaction respectively with maintenance procedures. The study suggested periodic assessments and, development of maintenance policies.

Keywords: Condition of housing, Maintenance, Procedures, Facilities.

Nijerya Üniversitesi Personel Lojmanlarında Konut Durumu ve Bakım Uygulamalarının Değerlendirilmesi: İlorin Üniversitesi Örneği

Özet: Özellikle Nijerya'nın yüksek öğrenim kurumlarında personel lojmanlarının sağlanması gerçekçi olmaktan çıkmakta ve mevcut lojmanların etkin bir şekilde bakımının yapılmasına ihtiyaç duyulmaktadır. Bu çalışma, personel lojmanlarındaki konut ve bakım uygulamalarının durumunu araştırmaktadır. Araştırmada, İlorin Üniversitesi lojmanlarındaki personelden anket yoluyla toplanan birincil ve ikincil bilgi kaynakları kullanılmış, 234 örneklem çerçevesinden 117 örneklem büyüklüğü rastgele seçilmiştir. Konut sakinlerinin sosyo-kültürel özellikleri, konut tipolojisi, tesislerin durumu ve bakım prosedürü gibi birincil veriler toplanmıştır. Analiz için Sosyal Bilimler için İstatistik Paketi (SPSS) kullanılırken, bulguların sunumunda frekans sayısı, yüzdelere ve tablolardan yararlanılmıştır. Çalışma, temellerin %53'ünün, zeminin %43,6'sının iyi durumda olduğunu, duvarların %47,7'sinin kötü durumda olduğunu, bakım prosedürlerinden %40,2'sinin memnuniyetsizlik, %29,1'inin memnuniyet gösterdiğini ortaya koymuştur. Çalışma, periyodik değerlendirmeler yapılmasını ve bakım politikalarının geliştirilmesini önermektedir.

Anahtar kelimeler: Konutların Durumu, Bakım, Prosedürler, Tesisler.

1. INTRODUCTION

With the growing population and increase in the government debt profile in underdeveloped and developing nations, the provision of staff quarters, particularly in Nigeria's tertiary institutions of learning is becoming unrealistic, the need for the efficient maintenance of existing properties has become more apparent and burdensome, calling into question the management and maintenance abilities of the current property managers [1]. Without a comparable expansion of infrastructure to fulfill the demand, such as staff accommodation close to the campus, the total number of students enrolled in various Nigerian educational institutions has recently expanded many times above their original estimated capacity. While it is true that the use intensity and the rate at which real estate degrades are significantly correlated. Additionally, effective maintenance of existing staff housing and its execution could make a difference [2].

An enormous portion of a country's investment goes toward its infrastructure [3]. These facilities, which include public buildings, must be maintained to code to fulfill their intended aesthetic and architectural functions [4]. An important characteristic of a developed country is its well-maintained infrastructure, which contributes significantly to any nation's socioeconomic development [5]. As a result, many developed countries have robust infrastructures, something they depend on to generate income for their local economies, and many countries take care to maintain their infrastructure and rely on it to draw tourists and generate income [3].

Numerous developed educational institutions in several Asian and European countries with adequate infrastructures draw many Nigerians to those regions, where they spend astronomical sums of money to further their education [5]. However, regular maintenance has proven difficult in Nigerian institutions because of issues including corruption, inadequate funding, bribery, and residents' irresponsible usage of facilities [6]. There are numerous expensive construction projects underway in Nigeria. This calls for rigorous consideration of construction management procedures to avoid damaging effects on the infrastructure.

According to [7], maintenance is the series of actions taken to care for a building, ensure its intended functions, and ensure its best performance over its lifetime. The term "maintenance" was defined by [8] as "the sum of all technical and administrative procedures, including supervisory measures, designed to maintain or restore an item to a state in which it can perform a specified function." According to [9], the totality of the activities performed to preserve or repair something is called maintenance. Building usage is improved by maintenance, resulting in the greatest safety standards. However, building upkeep is expensive from both a monetary and an environmental standpoint [7].

Many public buildings are not kept up to date [10]. Such interior elements, such as the floors, ceilings, doors, and windows, frequently show neglect [6]. Since their construction, some public institutions' residential and office buildings have not undergone any significant maintenance. Due to this, several of these structures are completely abandoned and in a state of disrepair. As a result, the lifespan of such buildings is reduced due to the routine occupant and government neglect of these facilities [11].

Maintaining university structures is necessary to create an environment that fosters creative teaching, learning, and research [12]. Authorities are very concerned about the nature of the relationship between staff and their working environment, and they all agree that a conducive environment has a positive impact on a staff member's ability to perform, all other things being equal [13]. Nonetheless, it seems like authorities are more focused on constructing new buildings while ignoring the demolition of existing ones. Therefore, it is crucial to note that the primary goal of managing educational properties should be to improve the welfare of both students and teaching staff, as well as other supporting staff. To do this, the

management of educational properties should make sure that these properties are created, built, and maintained in good, functional, aesthetic, and structural conditions. An educational institution's image in relation to services, architectural quality, and aesthetics will, to a large extent, be reflected in the standard and appearance of the structures and facilities that are located there [3].

1.1. Staff Housing

Staff housing in higher institutions refers to the housing provided by the institution for its employees, particularly faculty and staff. This housing is usually located on or near the institution's campus and is intended to provide affordable, convenient housing for employees. There are several reasons why higher institutions may choose to provide staff housing. One reason is to attract and retain talented faculty and staff by offering affordable housing in a competitive housing market [14]. Another reason is to ensure that faculty and staff have access to safe, secure housing that meets their needs. The background of staff housing at Nigerian universities can be traced back to the early days of the country's universities. In 1948, the University of Ibadan was founded. staff housing was provided for the institution's senior academic staff [15]. However, it was not until the 1970s and 1980s that staff housing became more widespread in Nigeria's higher institutions. During this period, the federal government launched a program to provide housing for its civil servants, including university staff [16]. Under this program, the government provided funds for the construction of staff housing in higher institutions, and many universities took advantage of these funds to build housing for their employees [17]. In some cases, universities also partnered with private developers to build staff housing.

Staff housing can take many forms, including apartments, townhouses, and single-family homes. In some cases, staff housing may be subsidized by the institution, while in others, employees may pay market rates for their housing. The typology of staff housing in Nigerian higher institutions can vary depending on the institution and its location. However, some common types of staff housing are found in many institutions across the country [18]. Bungalows are single-story houses that usually have two or three bedrooms, a living room, a kitchen, and one or two bathrooms. Bungalows are commonly provided for senior staff members who require more space and privacy [15]. Blocks of flats are multi-storey buildings that contain several individual apartments, with each apartment typically having two or three bedrooms, a living room, a kitchen, and one or two bathrooms. Blocks of flats are often provided for junior staff members and can be more affordable than bungalows.

Duplexes are two-story houses that are often provided for senior staff members or staff members with larger families. Duplexes typically have four or more bedrooms, a living room, a kitchen, and two or more bathrooms. Hostels may also be provided for staff members who are single or who do not have families. Hostels typically consist of individual rooms with shared living spaces and facilities [17].

Overall, staff housing can be an important benefit for higher institution employees, particularly those who are new to the area or who may have difficulty finding affordable housing on their own. Today, staff housing remains an important benefit for employees of Nigerian higher institutions, particularly as the cost of housing continues to rise in many parts of the country [19]. However, challenges remain, including the need for more funding to maintain and expand existing housing, and the need to ensure that housing is allocated fairly and transparently to eligible staff [20].

1.2. Pubic Building Maintenance

Varied people have different definitions of property maintenance. Different authors have provided definitions and redefinitions for the term. However, it appears from the numerous definitions that building upkeep is central to property maintenance. However, definition of maintenance is the necessary procedures carried out to maintain, safeguard, improve, and take care of hospital buildings and services after they are

completed by the applicable standards to ensure that they can perform their intended functions for the duration of their lives without significantly changing their fundamental characteristics and use [12]. Controlling the rate at which a structure deteriorates into an unusable state and eventually collapses is the art of maintenance. A county's progress is frequently gauged by the rate of expansion in housing construction, which has increased the number of contemporary homes [13]. Therefore, to keep up with the trend of construction, more maintenance work is needed. Additional upkeep, repair, and remodeling work are now required to ensure the use and security of the built homes due to the expansion in housing and the absence of building regulations. Additionally, it is important to maintain the current homes for as long as feasible.

Therefore, techniques for lowering maintenance costs should be developed [18]. Identified the following conditions as impacting how well public building standards are maintained: structural condition, roof condition, restrooms, water component, waste discharge, outside wall condition, building premise walkway condition, status of electrical wires and switches, and interior wall surface condition [21]. One of Nigeria's largest economic and social issues is the "I do not care" mentality and poor maintenance culture, which are like a sickness that has gnawed at the country's core and is shown in the way public facilities are run [22]. Without any management, structures are constructed and assumed to last their intended lifetimes. As a result, numerous studies on public building maintenance have been carried out, one of which is a study by [23] that examines how much each of the following elements contributes to maintenance issues in Nigerian Buildings housing government offices: Bad design, usage of subpar components and materials, inadequate electrical and mechanical design, insufficient mechanical, electrical, and structural design, inadequate electrical design, inadequate architecture design, natural deterioration brought on by age, surroundings, occupant abuse, and others 5%. [24], on the other hand, strongly disagree with the notion that the status of Nigeria's public buildings is due to inadequate funding and instead contend that corruption by powerful figures in the public sector is to blame. Nigeria was ranked number 2.4 out of 174 nations in terms of perceived public sector corruption in 2010, with a scale of 10 (very clean) to 0 (extremely corrupt). This demonstrates unequivocally the high level of corruption practiced by public servants. Most public institutions are unstable and have failed as a result of corruption, particularly in the public sector.

Examined the potential of efficient maintenance techniques as a means of maintaining housing supply during recessions [25]. This research modified a survey methodology, and its findings showed that the operational performance of public services and buildings is above average in terms of maintenance. In terms of their operational state, the structure and fabric (such as block walls, floor slabs, beams and columns, and roof structure) received high marks. Because the buildings were strategically placed, there was enough airflow for the operations to run well. Most public facilities have a good supply of clean water and a well-kept atmosphere. The majority of the interior components, including the paint, tile, door, ceiling, and windows, were likewise found to be in above-average operating condition. Both humidity and noise levels are well-controlled. The utilization of elevators (vertical transportation), fire prevention, telecommunications systems, and electrical supply were among other factors with very high performance ratings. The performance of the federal and state-owned buildings gave the structure and fabric very excellent ratings. Both gave very poor performance ratings to the utilization of elevators, telecommunications, electricity, and bathroom fixtures. According to the results of the hypothesis test, there is a big difference between federally-owned buildings and state-owned structures in southwest Nigeria in terms of how well they are operating, including their service.

A study on integrating sustainable facilities management into the administration of public buildings in Nigeria was conducted by [26]. The study used a questionnaire, and it discovered that the average state of public buildings in Nigeria is fair due to a lack of/poor maintenance plans for preserving them (on a scale of 1-poor to 5-excellent). In Penang, Malaysia, [27] conducted research on the assessment of factors

influencing building upkeep and flaws. The research project adopted the use of structured questionnaires while in their findings, lack of preventive maintenance and insufficient funds to maintain the building, lack of building maintenance standards, non-availability of replacement parts and components, and not responding to maintenance requests within the first to a fifth ranking rating of major reasons. While the most important variables for building defects were also included, they included poor building care, neglected site conditions, subpar materials, unfavorable environmental conditions, and moisture from damp areas.

Conducted a study on the Gaza Strip's operational maintenance of public structures [28]. The research's objective is to evaluate the management and maintenance procedures now used in public buildings in the Gaza Strip. The study used a questionnaire survey, and the findings provide a summary of the current state of the repair process in public buildings in the Gaza Strip. The research found that just three hospitals combine preventative maintenance with corrective maintenance, while corrective maintenance is practiced in all 13 public buildings. Additionally, their findings demonstrate that the majority of buildings in the Gaza Strip lack quality control systems for repair and preventative maintenance as well as maintenance plans for medical equipment. Employing experienced maintenance personnel is advised to create an adequate maintenance plan and thorough checklist, both of which are necessary for preventive maintenance. To increase their employees' efficacy and efficiency, management should set up specialist maintenance management training courses. Buildings in Gaza should make sure that all of their spare parts are on hand in their storage areas so that they can act quickly when necessary.

Additionally, [29] evaluated the efficiency of maintenance procedures in public schools. The study used a qualitative framework. However, a case study design approach was used for this study's investigation of the effectiveness of maintenance practices in public schools, specifically about Shehu Shagari College of Education in Sokoto. The study's conclusions showed that leaking roofs, faded paint, and cracks in the flooring and walls are the most prevalent maintenance issues. Due to two main factors—building pressure, misuse of facilities by some users, and poor management—building maintenance issues are more severe in the dormitory and staff quarters than in the classrooms and offices. Finally, poor labor management relations, poor management, a lack of funding, and improper maintenance practices are a few factors that affect maintenance management issues. According to the study, preventive maintenance practices should be adopted by the institution as opposed to ad hoc maintenance, as a primary focus. Building managers can anticipate future maintenance requirements and reduce unnecessary spending by including preventative maintenance chores into a work-order system, keeping systematic maintenance records, either manually or electronically, and scheduling building inspections.

1.3. Maintenance Practice

Buildings must provide a cozy and safe setting for a variety of Human actions. Essentially, the issue at hand is one of function [30]. Public buildings are in extremely bad and abhorrent structural and aesthetic states. Despite the millions of Naira invested to develop all of these structures, they are left to suffer from premature but continuous and quick degradation, decay, and dilapidation as soon as they are put into use [6].

Conducted a study on the upkeep of university housing in Nigeria [31]. Data from the research were analyzed using descriptive statistics. Their research showed that the majority of respondents engaged in some sort of maintenance activity. The key element affecting the practice of maintenance among the concerned staff is that the majority lack maintenance manuals and enough funding from the university administration. They concluded that the majority of the university residence halls in the study region have issues with maintenance management. The majority of the residential structures in the research area do not

have maintenance manuals, according to the respondents, who stated that they have all performed maintenance tasks at some point.

Additionally, [32] study evaluated the issues with Nigerian commercial property management practices. For analysis, the study used the relative significance index (R II), mean and proportion methods, and the descriptive method of percentages. The study also discovered that the major elements or issues that were considered to be issued with managing commercial properties in the state of Lagos were, in order of importance, high rent, the need for plumbing and power, ongoing maintenance problems, cash flow needs, and building expenses, all of which had positive relative importance indices of 1.8, 0.98, 0.75, and 0.65, respectively.

An investigation into the impact of maintenance culture on residential building construction in Nigeria were done by [3]. Both Primary and secondary sources were both used in this study. While the secondary source was collected from published and unpublished papers connected to the study, the primary source mostly comprises physical observation of the buildings. According to the findings, several factors contribute to maintenance issues in residential buildings in Nigeria, including inadequate funding, delays in the release of funds for maintenance, poor workmanship, natural effects like temperature, moisture, gaseous constituents, and pollutants, subpar materials, design flaws, natural deterioration due to age and environments, and a lack of maintenance culture.

The majority of maintenance managers while holding highly regarded certifications, were found to be lacking in their ability to apply quality improvement principles to maintenance operations due to a lack of sufficient professional workshops, training, and awareness campaigns. The researcher generally concurs with the findings, particularly in the areas where unqualified, poorly trained, and unprofessional personnel predominate. In Nigeria, maintenance personnel are frequently hired without regard to their qualifications or field, and they occasionally even come from unrelated professions. They are also not given any workshop training for maintenance awareness.

Conducted yet another study on maintenance management procedures for building facilities at eight polytechnics in Malaysia [33]. The study, which found poor service delivery, insufficient funding, poor maintenance planning, and maintenance backlogs, employed the usual approach practice. Additionally, there is a need to address the lack of maintenance management practice expertise that existed throughout all eight polytechnics. They concluded that the case study's key issues were non-specific complaints, repeated defects, tight budgets, long wait times for building repairs, and underqualified staff. Less human competencies can result in subpar service delivery, subpar maintenance planning, and maintenance backlog, according to the researcher.

1.4. Maintenance Management

Public building maintenance management is one of the more challenging topics in the field of facilities management [6] The intricate design of public structures, their fragile mechanical and electrical systems, and insufficient maintenance funds all contribute to this. the physical characteristics of the environment in which employees reside, employee contentment, and organizational productivity. These outcomes may be favorable or unfavorable.

In light of the aforementioned, numerous studies on maintenance management have been carried out, one of which was [34] study on the systematic management of building maintenance. The study also found that while there is insufficient spending on maintenance, there is also insufficient management of the resources and maintenance services, both of which have a significant impact on poor service delivery. According to the study's findings, a structure may only be considered valuable if it continues to offer the desired services

satisfactorily; otherwise, its existence will be irrelevant, if not completely useless. The researcher concurs with the conclusion that inadequate resource management and maintenance services have a significant role in the delivery of subpar services.

Another study on knowledge management application by [35] will help to improve the efficiency of Kuwait's building maintenance procedure. The study used field data and a survey approach, and it discovered that the suggested knowledge The type of contract will determine the knowledge management system that will be based on the type of contract that is most frequently used by public organizations. The researcher concluded that Kuwait's public building maintenance industry has several problems that hinder performance efficiency. The value for money spent by governmental agencies can be increased by implementing the knowledge idea and its associated tools and by creating a knowledge management system. The researcher concurs that the majority of public organizations employ knowledge management systems.

2. METHOD

2.1. Study Area

The city is a cultural melting pot where residents and visitors from all over Nigeria, including the Yoruba, Fulani, Nupe, Bariba, Kanuri, Igbo, and Hausa ethnic groups, live [36]. The city is home to sizable Muslim and Christian communities, and it hosts a variety of ceremonial events throughout the year, many of which have religious connotations. Ilorin is referred to as the "Home of Peace" and is the location of numerous educational and religious organizations, including the United Missionary Theological College, which grants degrees and is affiliated with the Universities of Ibadan and Ilorin. This institution produces numerous church ministers, educators, and theologians of all denominations.

Muslims are trained in a variety of Islamic, Arabic, and social science fields at the College of Arabic and Islamic Legal Studies in the Adeta region [37]. The University of Ilorin and Al-Hikmah University, Ilorin are only two of the universities that call Ilorin home. Kwara State University is located in Malete, outside the city's metropolitan area. Additionally situated there are Kwara State College of Education, Kwara State Polytechnic, Emmanuel Baptist College, Kwara State College of Arabic and Islamic Legal Studies, and Unilorin Secondary School. [36].

The Federal Government of Nigeria owns UNILORIN, also referred to as the University of Ilorin, is a university in Ilorin, Kwara State. It was established by a decree issued by the federal military administration in August 1975. The project made an effort to implement one of the Third National Development Plan's educational objectives, which was intended to provide opportunities for Nigerians interested in pursuing higher education and to develop the highly skilled labour so essential for the rapidly expanding economy of the country. When compared to other higher education institutions around the country, the university has one of the largest land areas, roughly 15,000 hectares. There are several housing units at the University of Ilorin Staff Quarters Permanent Site, all of which have different housing unit typologies. The staff quarters are essential for housing university staff members and supporting the institution's general community. The University of Ilorin has 234 housing units in total, comprising staff quarters for senior and junior staff on the main campus, staff quarters for GRA, and staff quarters for Mini Campus workers beyond the school's limits. The school's administration maintains the professorial suites, lock-up garages, and three to four-bedroom flats that are connected to the boys' quarters in both old and new bungalows for the personnel.

2.2. Method of Data Collection

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The study adopted quantitative research, designed both primary and secondary sources of information were used. In order to give a thorough explanation of the topic of the study and boost confidence in the reliability of the research findings and conclusion, primary data collection involves gathering first-hand information about the issue from the field using a structured questionnaire. However, direct observation of the houses in selected staff quarters by the researchers was employed to obtain information about the houses' physical attributes. while the interview was conducted with the Estate Manager of the university on the maintenance procedure used in the staff quarters. Secondary data were obtained from archival sources and included the total number of staff houses in the staff quarters. Residents of the University of Ilorin Staff Quarters make up the study's population.

A multistage sampling technique was adopted for this study. The first stage is the identification of staff quarters at the University of Ilorin. The second stage is breaking down the housing facilities into different typologies. The third stage involves the selection of 50% of each resident of the staff quarters. 117 sets of questionnaires were administered to the occupants of the University of Ilorin Staff Quarters. The study upheld the confidentiality of the participants' names from whom the data was gathered by the data protection policy, as shown in Table 1.

Table 1. Sampling and Sample Size

S/N	Name of the Quarters	Location	Housing Type	Number of Housing units	Sample Size (50%)
1	Senior staff Quarters	Permanent Site	3-bedroom bungalows attached with a lock-up garage and 1-bedroom boys' quarters,	80	40
			4-bedroom bungalows attached with a lock-up garage and 1-bedroom boys' quarters,	18	9
			Professorial suites (5-bedroom detached, 2-room guest chalet, boys' quarters, and lock-up garage	7	3
2	Junior Staff Quarters	Permanent Site	Semi-detached 2=bedroom bungalows	70	35
3	GRA Quarters	GRA	3-bedroom bungalows attached with a lock-up garage and 2-bedroom boys' quarters	7	3
			Professorial detached suites with a 2-bedroom guest chalet and a lock-up garage	7	4
				42	21
			3-bedroom bungalows attached with a lock-up garage and 1 room boys' quarters,		
4	Mini Campus Quarters	Mini Campus	3-bedroom bungalows attached with a lock-up garage and 2-room boys' quarters,	3	2
			Total	234	117

Source: Author's Fieldwork (2024)

2.3. Method of Data Analysis

Data collected for the study were analyzed with descriptive and inferential statistical analyses. Descriptive statistics, such as frequency counts and percentages, were adopted

3. RESULTS AND DISCUSSION

3.1. Socio-Cultural Background of the Residents of the Staff Quarters

The results on the socio-cultural background of the residents show that 56.4% of the respondents were male, while 43.6% were female. The study findings indicate that the respondents comprise 56.4% males and 43.6% females. In terms of age groups, the majority (50.4%) fall within the 26-40 years bracket, while 38.5% are above 40 years old. Only a small percentage (11.1%) are young adults between 18-25 years old. Regarding religion, the majority of the respondents (54.7%) practice Islam, while 45.3% practice Christianity. None of the respondents indicated following any other religion. The data presented in Table 2 also provides insights into the educational qualifications of the respondents. It shows that the majority of the respondents (39.3%) held a graduate degree, either a Higher National Diploma (HND) or a Bachelor's degree. A significant portion (25.6%) possessed a Master's degree, indicating a higher level of educational attainment. Furthermore, 19.7% of the respondents had obtained a National Diploma (ND) or a Nigerian Certificate in Education (NCE). A smaller proportion (11.1%) held a doctoral degree (PhD), demonstrating an advanced level of academic qualification. Lastly, 4.3% of the respondents had completed their education with a school certificate.

Table 2. Socio-Cultural Background of the Residents of the Staff Quarters

	Variables	Frequency	Percentage (%)
Sex	Male	66	56.4
	Female	51	43.6
	Total	117	100
Age Group	18-25	13	11.1
	26-40	59	50.4
	Above 40	45	38.5
	Total	117	100
Religion	Islam	64	54.7
	Christianity	53	45.3
	Total	117	100
Educational level	SSCE	5	4.3
	ND/NCE	23	19.7
	HND/BSC	46	39.3
	MSc.	30	25.6
	PhD	13	11.1
	Total	117	100
Employment Cadre	Academic	90	76.9
	Non- Academic	27	24.1
	Total	117	100
Staff Level	Senior Staff	101	86.4
	Junior Staff	16	13.6
	Total	117	100

Source: Author's Fieldwork, (2024)

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About the composition of the respondents in terms of their employment nature. It reveals that the majority of the respondents (76.9%) were academic staff, while 23.1% were non-academic staff. In total, this equates to 90 academic staff members and 27 non-academic staff members. This distribution reflects the diversity of job roles and responsibilities among the staff members residing in the University of Ilorin staff quarters. The distribution of the respondents based on their staff category. It shows that 86.4% of the respondents were classified as senior staff, while 13.6% were categorized as junior staff of the University of Ilorin. This distribution suggests a relatively balanced representation of both senior and junior staff members residing in the staff quarters.

Also, residential preferences of the respondents. It reveals that a significant majority (84.6%) expressed a preference to stay on campus. This indicates that the majority of the respondents favored the convenience and proximity to university facilities and activities that living on campus offers. However, a notable portion (15.4%) indicated a preference to stay off campus, suggesting a variety of personal reasons or specific circumstances influencing their housing preferences. The data underscores the diversity among the staff members and their varying needs and preferences, which should be taken into consideration when designing and managing staff housing facilities at the university

3.2. Housing Typology in Staff Quarters of the University of Ilorin

The data analysis reveals that the majority of the respondents (76.1%) reside in bungalows, while 17.9% live in blocks of flats. Interestingly, none of the respondents indicated living in hostels or duplexes. This suggests that bungalows and blocks of flats are the predominant housing typologies within the staff quarters at the University of Ilorin. As revealed in Table 3, 66 (56.4%) which represent most of the respondents reside in a 3-bedroom, 39 (33.3%) are staying in a 2-bedroom, 9 (7.7%) reside in a 4-bedroom while only 3 of the respondents reside in a 5-bedroom

Table 3. Housing Typology and Bedrooms Number in Staff Quarters of the University of Ilorin

Housing Typology	Frequency	Percentage
Bungalows	89	76.1
Blocks of flats storey building	21	17.9
Duplexes	0	0
Hostels	0	0
Professorial Suites	7	6
Total	117	100
Number of Bedrooms in Staff Quarters of the Respondents		
Bedrooms	Frequency	Percentage
2-bedroom	39	33.3
3-bedroom	66	56.4
4-bedroom	9	7.7
5-bedroom	3	2.6
Total	117	100

Source: Author's Fieldwork, (2024)

3.3. Staff Quarters' Housing Condition at the University of Ilorin

Table 4. reveals that in terms of housing components, 53% of the respondents indicated that the foundation is in good condition, 43.6% also pointed out that the floor condition is good and 47.7% revealed that the staff quarters wall is in fair condition. The window, door and ceiling are in good condition as indicated by

59.1%, 28.2% and 42.7% respectively. In terms of infrastructure in the staff quarters, Water supply and electricity are in good condition as indicated by 44.4% and 49.5% of the respondents respectively. 50.4% of the respondents indicated that the road was in fair condition, 38.5% indicated drainages were in very good condition and 33.3% of the respondents indicated that the sewage and waste disposal facility is bad, this is also corroborated by the observation as shown in figure 1 below

Table 4. Staff Quarters' Housing Condition at the University of Ilorin

S/N	Variables	Conditions				
		Very Good	Good	Fair	Bad	Very Bad
A	Foundation	9 (7.7%)	62 (53%)	38 (32.5%)	5 (4.3%)	3 (2.5%)
	Floor	18 (15.5%)	51 (43.6%)	39 (33.3%)	7 (5.9%)	2 (1.7%)
	Wall	16 (13.7%)	43 (36.8%)	56 (47.7%)	1 (0.9%)	1 (0.9%)
	Window	21 (17.9%)	69 (59.1%)	15 (12.8%)	7 (5.9%)	5 (4.3%)
	Door	32 (27.4%)	33 (28.2%)	29 (24.7%)	18 (15.4%)	5 (4.3%)
	Ceiling	39 (33.3%)	50 (42.7%)	19 (16.4%)	7 (5.9%)	2 (1.7%)
	Roof	29 (24.8%)	38 (32.5%)	41 (35%)	5 (4.3%)	4 (3.4%)
B	Water Supply	31 (26.5%)	52 (44.4)	24 (20.7%)	7 (5.9%)	3 (2.5%)
	Road	11 (9.4%)	21 (17.9%)	59 (50.4%)	16 (13.7%)	10 (8.6)
	Drainage	45 (38.5%)	31 (26.5%)	19 (16.3%)	15 (12.8%)	7 (5.9%)
	Electricity	21 (17.9%)	58 (49.5%)	32 (27.4%)	5 (4.3%)	1 (0.9%)
	Sewage/waste disposal facility	7 (5.9%)	25 (21.5%)	31 (26.5%)	39 (33.3%)	15 (12.8%)

Source: Authors' fieldwork (2024)



Figure 1. Waste Disposal in the Study Area

Source: Authors' fieldwork (2024)

3.4. Maintenance Procedure and Level of Management Responsiveness at the University of Ilorin Staff Quarters

The Estate managers of the staff quarters in the university were interviewed to investigate the types of maintenance procedures adopted in the study area. It was revealed that the university only engaged in Corrective maintenance due to the nature of the funding for that purpose. On the responsiveness level of the Staff Quarters Management to maintenance problems, Figure 2 shows the responsiveness of the staff quarters management to maintenance requests. It reveals that 40.2% of the respondents are very unsatisfied with the responsiveness of the staff quarters management to maintenance requests, 29.1% indicated satisfied with the responsiveness of the staff quarters management to maintenance requests, 26.4% indicated very unsatisfied with the responsiveness of the staff quarters management to maintenance requests and 4.3% revealed that they are satisfied with the responsiveness of the staff quarters management to maintenance requests.

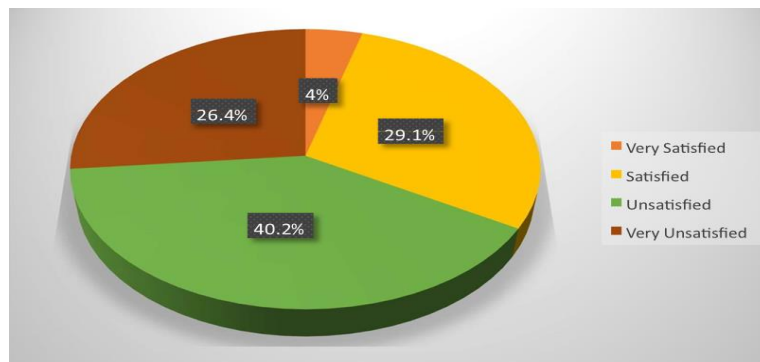


Figure 2. Responsiveness of the Staff Quarters Management
Source: Authors' fieldwork (2024)

4. CONCLUSION AND RECOMMENDATIONS

The study concluded that, the majority of respondents in the staff quarters reside in bungalows, indicating that bungalows are the predominant housing typology at the University of Ilorin. This information can guide future planning and allocation of housing units. Also, the socio-cultural background of the residents reveals a diverse community, with variations in gender, age, religion, and educational qualifications. Understanding these demographic characteristics is crucial for creating an inclusive and supportive living environment. The assessment of the housing condition highlights the need for attention to facilities maintenance and improvements in infrastructure especially sewage and refuse disposal facilities.

Periodic assessments of the housing condition should be conducted, and necessary upgrades and renovations should be planned and executed accordingly. This includes addressing issues related to infrastructure, utilities, and amenities to ensure that the housing facilities remain modern, functional, and comfortable. The University of Ilorin should develop a comprehensive maintenance policy specifically tailored to the staff quarters. This policy should outline routine maintenance procedures, establish clear responsibilities, and emphasize the importance of regular checks to ensure the timely identification and resolution of maintenance issues.

Establishing a resident representative council or committee can facilitate effective communication and collaboration between the staff quarters management and residents. This platform can serve as a forum for discussing concerns, sharing ideas, and working together to enhance the living experience in the staff quarters.

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Determining Design Criteria For Re-Connecting Muharraq City With The Waterfront



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Abstract: This paper focuses on the design considerations for city open space projects, especially those near waterfront projects. In this perspective, the objective is to discuss the expertise involved in dealing with the Sa'ada project Phase 2, which aims to establish a sustainable connection to the nearby waterfront projects via proposing an innovative concept of a pedestrian bridge connecting the adjacent Plaza in Muharraq City, Bahrain, to the nearby waterfront. The research methodology is qualitative analysis. Moreover, conducting focus group discussions with specialists will guide the research to embody Muharraq's heritage features, practical solutions for an innovative, sustainable pedestrian bridge and plaza, and foster the social uses of Muharraq's residents and tourists are critical points of discussion. The study provides design strategies for integrating regional identity with modern city development. Its findings can offer important implications for future urban development initiatives to vitalize urban areas design projects.

Keywords: Muharraq, Walkability, Commercial streets, Waterfront, Focus Group, Urban development.

Muharraq Şehrini Sahil Kenarıyla Tekrar Bağlamak İçin Tasarım Kriterlerinin Belirlenmesi

Özet: Bu makale, özellikle kıyı şeridi projelerine yakın olanlar olmak üzere, şehir açık alan projelerinin tasarım değerlendirmelerine odaklanmaktadır. Bu perspektifte, amaç, Bahreyn Muharrak Şehri'ndeki bitişik Plaza'yı yakındaki kıyı şeridine bağlayan yenilikçi bir yaya köprüsü konsepti önererek yakındaki kıyı şeridi projeleriyle sürdürülebilir bir bağlantı kurmayı amaçlayan Sa'ada projesi Aşama 2 ile ilgili uzmanlığı tartışmaktır. Araştırma metodolojisi nitel analizdir. Dahası, uzmanlarla odak grup tartışmaları yürütmek, araştırmayı Muharrak'ın miras özelliklerini somutlaştırmaya, yenilikçi, sürdürülebilir bir yaya köprüsü ve meydanı için pratik çözümlere ve Muharrak sakinlerinin ve turistlerinin sosyal kullanımlarını teşvik etmeye yönlendirecektir. Çalışma, bölgesel kimliği modern şehir gelişimiyle bütünleştirmek için tasarım stratejileri sunmaktadır. Bulguları, kentsel alanları canlandırmak için gelecekteki kentsel gelişim girişimleri için önemli çıkarımlar sunabilir.

Anahtar kelimeler: Muharrak, Yürünebilirlik, Ticari sokaklar, Kıyı şeridi, Odak Grup, Kentsel gelişim

1. INTRODUCTION

The Sa'ada Phase 2 is one of the new urban development plans for building a proper connection between the island of Muharraq and the sea. Muharraq is historically one of the oldest cities in Bahrain, and its urban fabric is distinctive for its cultural and historic attributes that have increasingly overloaded the traditional island trade and architectural identity [1]. Nevertheless, urban growth and transformation, as well as social and infrastructure development, including the construction of a major highway, have erased the links to the seashore and have housed barriers, both physically and metaphorically, between the historical core of the city and the waterfront. Understanding this need, the Sa'ada Phase 2 proposed plan includes a pedestrian

bridge and plaza with the intention of connecting the old city to Sa'ada Phase 1 located right across the highway at the waterfront. Its provision is aimed to contribute to building linkages, and, notably, the cultural identity of today's urban spaces in the framework of contemporary architecture and design.

The aim of this paper is to explore and analyze the design factors that would be directed at boosting the success rate of Sa'ada Phase 2 and thus revitalize the area. In general, this research seeks to discover the principles, design solutions, and qualitative characteristics in which the conceptual design of the pedestrian bridge and the plaza may express the Muharraq historical identity and at the same time fulfill the social and functional requirements in a new urban context. It also becomes important to find a balance between the need to retain the historic character of the area and the requirement for designing a walkable pedestrian environment of contemporary global standards in terms of comfort and safety [2]. To determine these requirements and challenges, a focus group method is carried out with stakeholders such as Academics, architects, urban planners, and cultural specialists. This cooperative process ensures that a common understanding of the design is developed through which potential design solutions can be explored, which take into account the respective cultural aspects and at the same time are functional.

The project's contribution was also studied using the method of SWOT analysis, of which the cumulative outcomes of urban connectivity were determined. The study reveals how the project would succeed and where potential risks lie by addressing social, economic, and environmental issues. The article mentions that master plan and urban design are among the issues that contribute to and hereby can play a role in the becoming of a more livable Muharraq in the perspective of a sustainable and climate-resilient future. The data from the study will enable the Bahrain government to redesign urban areas as well as other places under similar conditions in the future.

The following are the research questions this study poses:

- a. What are the most important design factors to take into account when designing a plaza and a pedestrian bridge to link Muharraq's waterfront with its historic urban core?
- b. What attributes and challenges are to be considered to make this project active and well-connected physically and visually with the surroundings and the waterfront?
- c. What are the characteristics of the proposed site that would make it a successful project?

By answering these questions, the study aims to offer a systematic analysis of how urban design can be utilized to enhance the connection between the past and the current architecture of Muharraq city. In this respect, the study is particularly concerned with designing a public space within Muharraq taking into consideration its culture and respective architecture with an appreciation of contemporary design standards of such spaces. The information gathered from the focus group discussions will be used in the creation of guidelines for design approach that will provide continuity in matters concerning aesthetics and architectural language in the face of modernity hence boosting up the Sa'ada Phase 2 project as a visionary development of a public hub connecting to waterfront in Bahrain and other heritage urban contexts. The research structure is shown in Figure 1. In general, this paper joins others in expanding the discussion of place-making in an urban context, highlighting the value of participatory approaches in shaping public spaces that honor the past while looking toward the future.

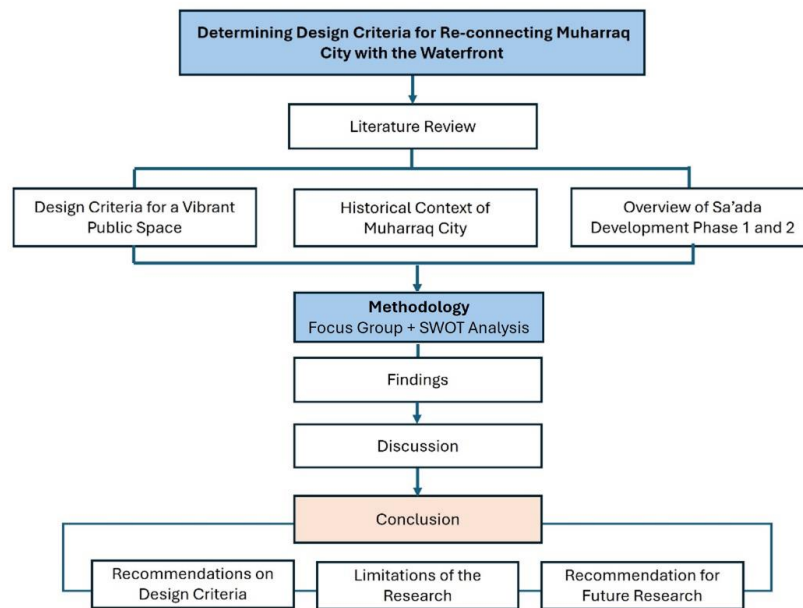


Figure 1. Research Structure (Developed by authors)

2. LITERATURE REVIEW

2.1. Design Criteria for a Vibrant Public Space

There has been a great acknowledgement of urban vibrancy from studies on emerging urban areas, attributing it to enhanced business activities and lots of social activities in the metropolitan areas [3]. This is provided in residential areas, commercial areas, historical and cultural sites, and recent thematic parks, among others. If these categories are not well-designed considering social interactions and cohesiveness across different societies, then their sustainability issue might be at stake.

Public space is an essential component, given that it makes cities sustainable and friendly for their inhabitants because that is where they interact. They also promote business, leisure, tourism, and numerous other uses [4]. While there has been continuing concern about studying the ways in which public spaces are employed, they recognize the threads of the urban texture. Nevertheless, the researchers in the field have always tried to guide the design through guidelines which direct them to quantify & qualify the properties of public space. Classical urban design texts like [5], [6], and [7] outline methodical analyses of varying degrees of vibrancy in urban public areas from the standpoint of social use, as well as how these relate to specific traits and architectural elements of these areas. Lynch stated his perception of comprehending the city space in his book titled “The Image of the City,” published in 1960. He divided the understanding of the built environment into five components which include Paths, Districts, Edge, Landmarks, and Nodes, as explained. Knowledge of these elements helps urban planners in creating pleasing, easier-to-navigate cities. More comprehensive models have recently been proposed to quantify, assess, and score public space qualities. [8] created a public space index based on 45 distinct characteristics in order to assess the quality of public space from five perspectives—inclusion, meaningful activities, comfort, safety, and pleasure. Some research focuses on how a small number of easily quantifiable factors affect human activity in public areas, such as entrances and the length of the street [9]. Using a variety of descriptors and indicators, including accessibility, ownership, inclusiveness, and management, [10] assessed public space according to the notion of publicity.

Historic zones keep the city's past and significantly reshape the present townscape [11]. However, the design and planning changes due to growing globalization have become a threat to the physical-aesthetic locales of towns all over the world [12]. It is difficult to conceptualize location as a notion without considering the issue of historical characteristics. This is because "place" is attached to "them being portrayed socially, physically, and in minds" [13]. The act of adorning a location's physical fabric, which forms the foundation of a successful social space, is known as "place-making" in the context of urban design [14].

According to [5], the main components of urban vitality are the necessity of small blocks, older buildings, people, and primary mixed-use [5]. In order to maintain, renew, or advance a lively urban life in large cities, Jacobs demonstrated that diversity is necessary at both the neighborhood and street levels in the physical environment. According to [15], Jacobs understands cities as places where the public is used as a meeting point, the streets are designed for pedestrians, and there are buildings with multiple functions that can facilitate many of the users' needs. While [16] found that there are four essentials from the perspective of diversity: land uses, compacted blocks, historically significant buildings, and higher building densities should all be present in physically diverse environments.

2.2. Historical Context of Muharraq City

Muharraq, which was previously a thriving center for natural pearls in the region which boosted the country's economy, making it the economic capital of the country. The intimate relationship that exists between Muharraq City and the waterfront was elaborated upon. Beginning with the name Bahrain, which refers to the country's undersea freshwater springs as well as its salty waters. The Arabic translation of the word means "two seas". Pearl harvesting has been a vital source of income for every segment of the economy since the beginning of the twentieth century, including creditors, merchants, brokers, suppliers, sailors, crew members, boat owners, and builders [17]. However, the pearling industry was affected negatively when cultured pearls started becoming popular in the 1930s, and at the same time the oil was discovered in Bahrain. Accordingly, Manama became the capital [18]. stated that this then led to homes being rented out to the expatriates and foreign laborers.

Muharraq's close relationship with the sea was broken when land was reclaimed (Figure 2). Most of Muharraq City's streets still have the same layout as they had during the Pearling era, despite a significant amount of new development. These alleyways are characterized by a network of tiny, frequently attractive passageways [19]. Muharraq's spirit was brought back to life when Sheikha Mai Al Khalifa's grandfather's ancient home was converted into the Sheikh Ebrahim Al Khalifa Centre for Culture and Research in early 2000s, hoping to revive Muharraq's cultural life, which had drastically fallen since the pearling industry's collapse [20].

A newly built tourist center on the seashore, three preserved oyster beds, and a maintained Bu Mahir fort are all part of the project, which involves the preservation and reconstruction of various man-made and natural features associated with the pearling trade. These structures are all interconnected along a unique trail known as the "Pearling Path," which tells the story of pearling and runs from the last coastline of Muharraq into the inland area. From the reclaimed area, a newly built pedestrian bridge (Figure 3a) leads to the old Muharraq, where a number of traditional buildings (Figure 3b) underwent restoration and rehabilitation [21].

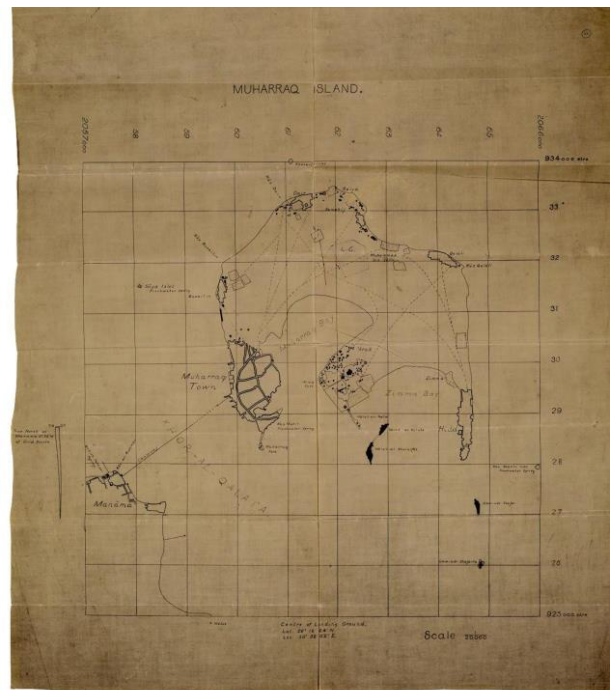


Figure 2. Old map of Muharraq City, Bahrain [21].



Figure 3a. Pedestrian bridge leading to old Muharraq historic sites (Source: By Authors)



Figure 3b. Traditional buildings and market (Souq) in Muharraq (Source: By Authors)

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The Pearling Path (Figure 4) was given the 2019 Aga Khan Award for its design, which was honored for the storytelling element through the use of the various themed components and the metaphor of the pearl in every part [22]. Many who had written before of their longing for older times and positive transformation showered local newspapers with expressions of gratitude for the project's accomplishment [23]. Reviving the local markets and people's culture and lifestyle are part of urban development, according to [24].

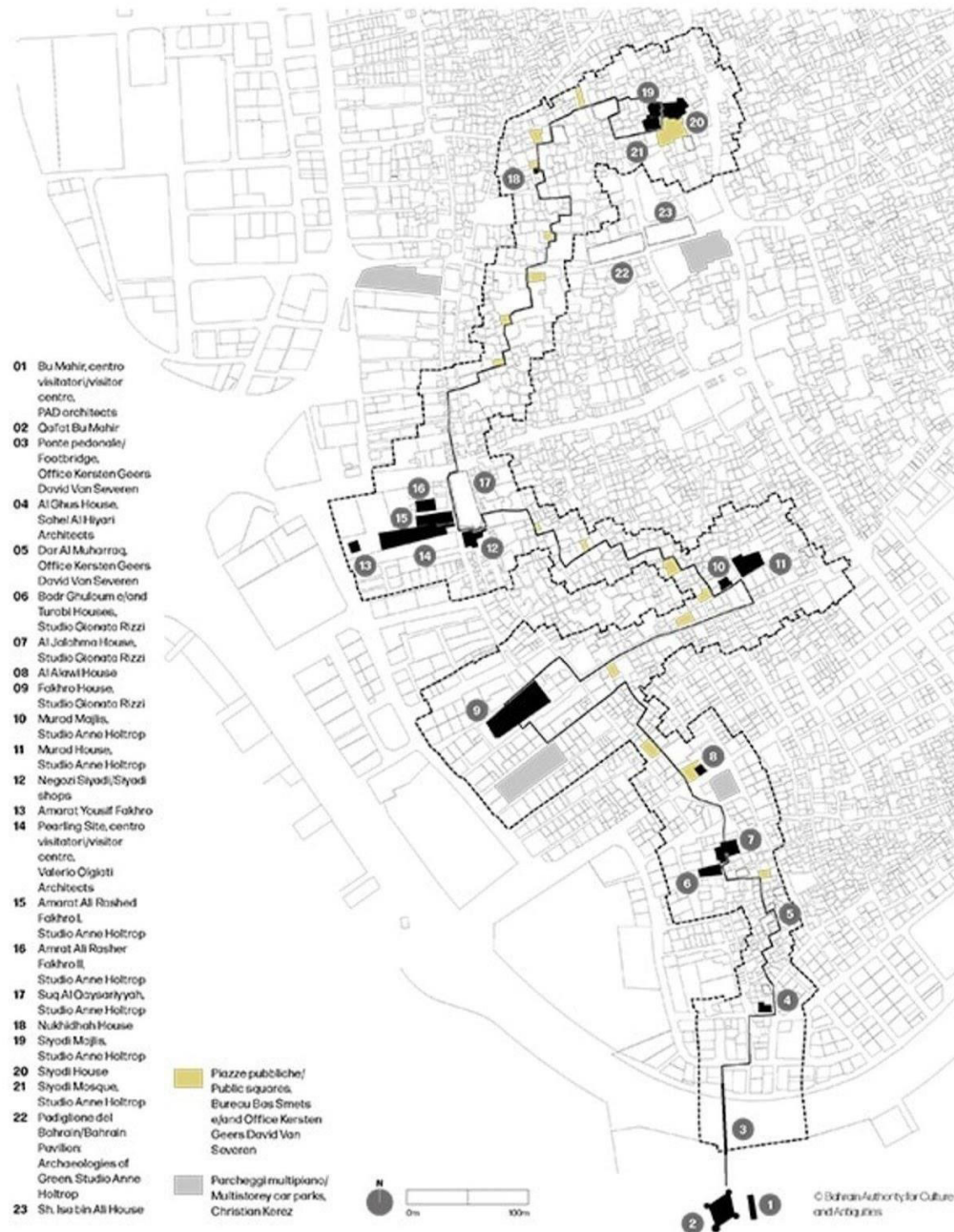


Figure 4. The Pearling Path Map at Muharraq city, Bahrain [7]

2.3. Overview of Sa'ada Development Phase 1 and 2

The Sa'ada waterfront development, situated in Muharraq, the first phase of which has been completed, and the second is expected to start, is one of the most prestigious projects in Bahrain. The Sa'ada project leads mixed-use development with an organic urban structure that covers the area with open places and buildings. The project studies the use of a linking approach to connect the Muharraq Souq and the old part of the city to the waterfront. The general design directs the urban image that is environmentally sustainable, including an aesthetically and functionally friendly space that is both peaceful and safe. The project's development goal is to develop a tourist attraction that offers seafront access to the historic core of Muharraq (Figure 5). The site is situated in the northeast of Bahrain, in the Muharraq neighborhood near the Sheikh Hamed Causeway, Al Ghous, and the Khalifa Al Kabeer highway interchange on both the east and west sides of the road. The plaza is located at a prime spot between the two main islands of the Kingdom. The existing F&B components of the project have an impact on the social and economic aspects of the area. The project is recognized for being an attraction due to its strategic location in Muharraq and connections with other developments.

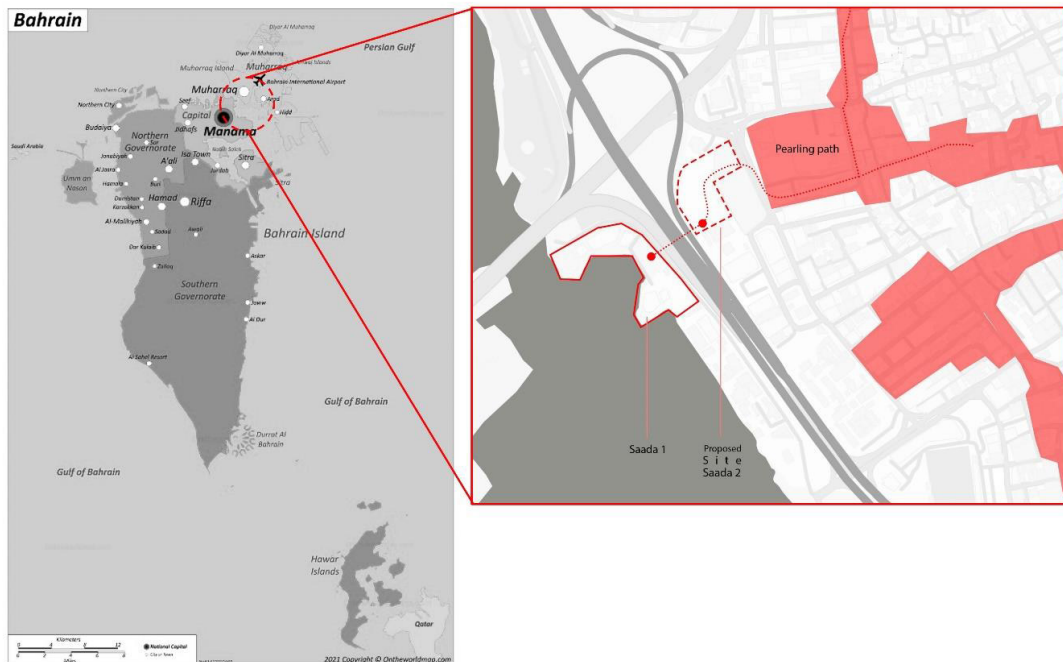


Figure 5. Sa'ada Waterfront Development – Phase 1 & 2 site location in reference to the Pearling Path. (edited By Authors)

Two main elements that link the past and present in Sa'ada Phase 1 mixed-use waterfront development concept are the combined image of the old souq in Muharraq and the Manama cityscape. The whole image of the diverse inspirational local architecture makes the development strive to be different and unique. Phase 1 of the project covers an area of 18,066 square meters which consists of 34 commercial units, including restaurants, retail, and entertainment venues. There are also 200 parking spaces and 36 marina bays [25]. Sa'ada's second phase is focused on three main goals: creating a development that will be profitable, bringing a marina center to the area, and—above all—creating a connection to the old side of Muharraq as a continuation of the Pearling Path project. The new phase links the first phase with Muharraq's Old Souk. The main component required for the second phase is a pedestrian bridge that connects the project's two segments.

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Parking is a problem for Muharraq Souq as well as Sa'ada's first phase. Therefore, the project's second phase, with an area of over 11,223 square meters (Figure 6), is set to enhance the location by including a multi-storey car park building, F&B outlets, retail and service shops, and open plazas. In addition to revitalizing the historic bus station and renovating the post office.



Figure 6. Sa'ada Waterfront Development – Phase 2 site location [edited by Authors]

3. MATERIAL AND METHODS

3.1. Focus Group

To ensure that the design criteria for the Sa'ada Phase 2 project received robust evaluation from various users, the Focus Group method was adopted as the qualitative research method in this study. Since focus groups are an excellent method for studying complex and nuanced topics, it is excellent for understanding how different members of the community and experts see the design of a public space that reconnects Muharraq to its waterfront. Using focus groups is a perfect technique to engage stakeholders within a group discussion forum where participants contribute their thoughts and also respond to other participants' views, in addition to exploring in more detail subjects in urban design studies, particularly those regarding culturally sensitive projects [25]. Academics, architects, urban planners, heritage specialists, and project developers are among the many stakeholders involved in the focus group discussion about Sa'ada Phase 2 project (Table 1), and each one offers unique insights into the cultural, functional, and aesthetic elements that are essential for the plaza and pedestrian bridge.

Table 1 . Focus Group Participants

	Name	Position
1	Prof. Islam Elghonaimy	Professor, Coordinator of Postgraduate programs – UOB
2	Dr. Souheil El Masri	Director, Architectural Design - Gulf House Engineering
3	Mr. Ahmed Arafa	Senior Design Manager – Gulf House Engineering
4	Mr. Haider Alnoaimi	Associate Director Operation – Architect - MSCEB
5	Prof. John Pierre El Asmar	PhD, DArch – Academic Vice President – Royal University for Women
6	Mr. Abdullah Isa Qudrat	Business Development Director - Amakin
7	Dr. Fatima Al Hammadi	Assistant Professor – Coordinator of Landscape Architecture Program - UOB
8	Sara Fareed Hussaini	Architect - BACA
9	Fatima Al Hayki	Architect - BACA
10	Ms. Afaf Ebrahim	PhD. Candidate - UOB
11	Mr. Isa Jalal	Business Development Officer - Amakin

After setting the date and time with all the invites, the focus group members confirmed their participation by email. A total of 11 members participated in a discussion that took approximately 1 hour and 30 minutes, excluding the introduction and closing of the session (Figure 7).



Figure 7. Focus Group Discussion (By authors)

This approach gives a proper understanding of stakeholders' needs to be met and issues that they hold while designing a public domain that needs to fulfill a balance between the historical importance of the area in today's functionality of a city. Unlike structured interviews, surveys, and exclusive interviews, this facilitates discourses that involve discussions that put into contemplation which are likely to lead to ideas that would not be suggested when in solitary. The other characteristic of focus groups is that they align with the project's aim as they seek to promote the activation of the community and ownership of the communal space. In addition, this approach allows for expressing opinions and presenting conflicting viewpoints, which the study can then shape to address a broad scope of real-world issues. Besides enhancing our understanding of specific design requirements, this technique also helps us to understand the values and expectations of the upcoming space users, thereby resulting in cultural and more community-oriented design criteria.

3.2. SWOT Analysis of 2nd Phase of Sa'ada Project

An Interview was conducted with one of the top management team to participate in the SWOT analysis [26]. As one of the key stakeholders in the project, Mr. R. H the head of asset management at Edamah, the Bahrain Real Estate Investment Company, which is the leading property developer in the kingdom. He was interviewed to gain the perspective of experts and to consider important information regarding the factors and dimensions mentioned, which will help in the decision-making considerations of the aspect that would determine the new project's phase. The SWOT analysis for the second phase of the Sa'ada waterfront development project based on the literature review and the interview with the developer, is outlined in Table 2:

Determining Design Criteria For Re-Connecting Muharraaq City With The Waterfront

Table 2. Criteria and dimensions of SWOT Analysis of 2nd phase of Sa'ada Project (by Author)

No	Factor	Element	Description	Results and conclusion of studying the second phase of Sa'ada project	Results and conclusion of studying the second phase of Sa'ada project	Results and conclusion of studying the second phase of Sa'ada project	Results and conclusion of studying the second phase of Sa'ada project
				Strengths	Strengths	Strengths	Strengths
1	Economic	a. Government Support (Developer – Top Management)	In terms of funding, regulations and policies	Transferring land ownership to Edamah			Delays in approvals might affect the project timeline
		b. Cost of construction (Developer-finance team)	Affordability of the project, availability of capital		High cost of construction – find an investor		
		c. Shifts of trends & Market change (Developer-Sales team)	Market stability, change of trends, commercial demands. Global economic downturn.				Impact on the capital expenditure cost, rental rates. This might affect the choice of tenants.
		d. Purchasing Power (Developer-Marketing team)	The purchasing power of customers and the demand of commercial brands				Low purchasing power affects the commercial viability of the project
		e. Investment opportunities (Developer-Investment team)	Collaboration with local businesses and international investors			Additional resources of funding and financial stability	Gentrification and over-commercialization
		f. Financial Status (Developer-finance + Sales team)	Success of first phase outcome and readiness financially for the 2 nd phase	The successful outcome of 1 st phase with 80% occupancy leads to a strong financial status to start the new phase			

2	Environmental	a. Location (Consultant + Physical Planning Directorate)	Accessibility, proximity to the surrounding features, orientation	Connection between the old Muharraq and the waterfront area	Limited to Muharraq area. Exposed to south orientation. Dense traffic with lack of parking spaces.	Tourists' attraction due to the link with the old souq and heritage areas.	
		b. Architectural Design and spatial layout (Consultant – Main architects)	Functional relationships between the facilities and ease of circulation pattern in the spatial layout	Innovative architectural elements increase the aesthetic appeal of the project	Limited circulation pattern in the spatial layout restricts the connections with the waterfront.		
		c. Sustainable solutions (Consultant – Main architects+ Engineers)	Integration of sustainable solutions in the design			Demand of sustainable solutions due to the orientation of the site facing the south	
		d. Components & features (Developer – project development team + Consultant – Main architects)	Fulfilling the needs of providing important components and facilities	Providing the features and facilities required for the area. Especially the carpark building.			
		e. Infrastructure (Ministry of Works + Consultant)	Provision of well-developed infrastructure in the area	Availability of well-developed infrastructure to receive the new phase of the project			
		f. Smart and technological systems (Consultant – Main architects+ Engineers)	Use of latest technologies in construction and operation of project.			Enhancing the facilities with the integration of smart solutions in operating the car park building	

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3	Social	a. Demand (Developer – project development & Investment team)	Responding to the demand of users and visitors. The need for the project	Increasing demand for phase 2 supports the initiation of the project			
		b. Social Interaction (Developer - Marketing team)	Facilities encouraging social attractiveness and interaction on site			Potential spaces to encourage social participation and interaction	
		c. Convenience (Consultant – Main architects+ Engineers)	Ease of accessibility, inclusive design, and comfort measures.	Easily accessed and inclusive design of site make the site more livable			
		d. Cultural aspects (Consultant – Main architects+ BACA)	Identity of place and cultural and history connection	Strong Identity and sense of place and cultural connection with heritage areas			
		e. Competition (Developer - Marketing team)	Emergence of other competitive projects				bigger scale projects such as Qalali waterfront project, the Wharf and the Park can attract visitors away from the site.
		f. Security & Safety aspects (Consultant – Main architects+ Engineers)	Provision of safe and protected spaces to give sense of security.			Well-designed spatial layout and integration of technology can enhance the sense of security.	

4. RESULTS

The key findings from the focus group discussions for the Sa'ada Phase 2 project reveal critical design criteria and challenges that need to be considered to ensure the project's success in reconnecting Muharraq's historic core with the waterfront. These findings are categorized as follows:

Cultural Sensitivity and identity of the place

There was a strong debate about using design features that reflect the cultural characteristics of Muharraq. According to the participants, this element should embody the traditional language of architecture and continuity with the place in terms of spatial configurations, construction material and typologies, the built environment typical of the historical cores, and the modernity of the new emerging constructions of the project area. They proposed the objectives to use features of modern forms that refer to the historical past of Muharraq's identity, making the space as natural as possible, and recalling the historic days of the city.

Accessibility and Inclusivity

During the discussion, the participants paid great attention to the question of accessibility and inclusiveness of the design. they recommended that the design should be friendly to wheelchair and pushchair users, those with impaired mobility, the elderly, and children by having ramps, handrails and slip-flooring, adequate seating, and shading; Information and signage should be in different languages for easy wayfinding and that the safety of pedestrians should be of utmost importance, however, sufficient carpark and services to be provided to compensate the lack of these provisions in the area.

Pedestrian Safety and Traffic Integration

The group also expressed safety concerns about linking the pedestrian bridge with the heavily busy highway between Sa'ada Phases 1 and 2. Some proposals were for the distinction of the roads used by pedestrians from other vehicles installation of cross signals or manage traffic efficiently. One of the participants suggested that the plaza be built at a higher level above the vehicle accesses. Such steps were considered necessary in order to avoid mishaps and guarantee users a smooth walkable experience.

Environmental and Climate Consideration

The Participants highlighted the necessity of climate-appropriate architectural design since a hot climate characterizes Bahrain. These included providing walkways with shades, constructing seating arrangements to shade them, and appropriately using materials during hot weather. Greenery was noted as having potential for cooling through improving microclimate as well as water features and the technology of outdoor cooling systems was proposed for both cooling and aesthetics to make the environment attractive and comfortable.

Functional and Socially Active Plaza

All the focus group participants agreed that the plaza should be filled with various social and cultural activities due to the absence of such places in the area. In order to make the plaza act as a social and cultural place where various activities would be organized to attract the residents as well as the tourists, it was suggested that well-maintained public toilets, public amenities, flexible furniture, art exhibitions, and cultural events, as well as social performances or market space, can be provided and organized in the space with the intention of improving the vitality of this area [17].

Connection with the Waterfront

To reconnect Muharraq with the sea, which has been an element of its identity and historical economy, participants suggested that the bridge should be designed with overlooks allowing people to look at the city and the sea. The importance of maintaining open access to the waterfront was highlighted in terms of physical and visual contact.

5. DISCUSSIONS

The focus group discussion findings for Sa'ada Phase 2 project highlight essential design criteria and challenges that align well with insights from existing literature on urban design in culturally significant and waterfront contexts (Figure 8). Particularly in heritage-rich cities locations, the literature analysis and focus group results emphasize the significance of environmental adaptation, inclusive accessibility, and culturally sensitive design. However, Muharraq's climate, urban difficulties, and historic fabric make it necessary to modify these general principles in particular ways. The implementation of successful, culturally sensitive solutions to the project's main design difficulties is made possible by comparing focus group results with existing literature.

Literature extensively stresses the necessity of preserving cultural identity in planning and design, especially in areas of cultural importance. According to [28] and [29] the design of public spaces in heritage areas must respect the place's local context, architectural typology, and history, which helps foster a sense of belonging among residents. The importance of the project in reflecting Muharraq's architectural identity was also emphasized by focus group participants, who offered inspiration from the traditional architectural language of Muharraq city, considering elements, materials, and spatial configuration. This aligns with the approach used in Al Seef and Dubai Creek Development of Dubai, United Arab Emirates, which uses modern and traditional architectural language. The work was completed in 2018 and respects the old Creek area of Dubai with a public pedestrian zone, commercial, and cultural points of interest. The place was designed to resemble Dubai's old, restored Al Fahidi district with stone buildings, wind towers, and narrow shaded alleys. The Al Seef project reflects traditional Emirati architecture while seamlessly integrating into a modern part of the city that represents its development. Both aspects of blending old with new are made to interconnect and meet the needs and expectations of both local people and tourists, focusing on Dubai's cultural and modern profile [30]. For Sa'ada Phase 2, it might be possible to represent Muharraq's heritage without producing an imitative look by utilizing architectural elements, a traditional spatial layout, and historical references, ensuring the area seems incorporated rather than forced into its surroundings.

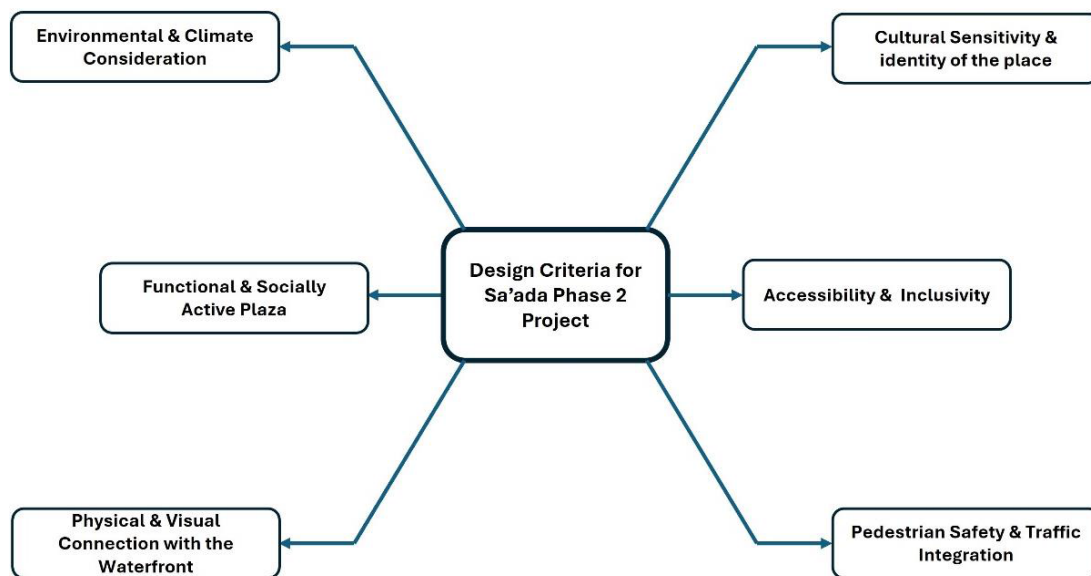


Figure 8. Design Criteria for Sa'ada Phase 2 Project as Suggested in the Focus Group Discussion.

When combined with the literature, the focus group highlighted the accessibility aspect as having implications for the design of public spaces. The three elements as specified by [31] Handrails, ramps, and clear signage should be made to be a part of the design so that members of the community with disabilities and all ages will be able to access the urban spaces. The Provision River Pedestrian Bridge in the United States is a good example of a pedestrian bridge that meets a variety of user requirements by including ramps, accessible paved routes, and ample of benches [32] [33]. It played a significant part in combining the East and West Park into one coherent area of shared public use with elements of urban and natural landscapes envisioned by the master plan. In addition, the bridge magnifies the connectivity of residential districts, commerce, tourism, and culture. It creates the possibility of environmental interpretive nodes that teach locals and tourists about the ecology and history of the urban area. Similar components could be used for Sa'ada Phase 2 to guarantee that the area stays friendly and inclusive.

Literature regarding pedestrian infrastructure in large urban spaces corresponds with the focus group's safety concerns, particularly concerning the highway separating Sa'ada Phases 1 and 2. When developing areas within close proximity to main highways, [34] Emphasized the importance of traffic mitigation measures and pedestrian crossings. As suggested by the focus group participants, Sa'ada Phase 2 may include an elevated pedestrian bridge, which will enable safe and continuous pedestrian connectivity between Phase 1 and Phase 2 without interruptions or crossing dangerous roads. This will allow for uninterrupted pedestrian mobility between the two sites of Sa'ada. Other safety measures that may be added include greenery barriers, lighting, and signals.

One of the group discussion findings was the challenges posed by Bahrain's hot climate, which has to be considered in the design to encourage walkability in the space. Literature reviews on climate-responsive urban design stressed elements such as shading, ventilation, and cooling systems. [35] described some strategies such as shaded pathways, integrated water features, and greenery to help mitigate the occurrence of the urban heat island effect. The focus group suggested that, in order to reduce the heat effect, planting native trees, green walls, or covered pathways should be considered in the design. In addition, thermal comfort could be improved by the use of features such as fountains that could serve as a focal point, or outdoor cooling systems in the plaza.

From the results of focus group sessions, participants pointed to the need to have a more active and socializing central area, which can accommodate the inhabitants, as well as visitors. Previous studies on urban plazas also promote the concept of versatile, engaging, or performable open spaces, which may represent leisure or culture [36]. To ensure that there is public participation and that the plaza is active, it was recommended that the plaza incorporate sitting areas, public toilets that should be well maintained, an area for holding community functions, open markets, and a space that could be used for art exhibitions. The plaza would help call for community usage by offering a fun and multi-use environment, fostering a sense of belonging and place identity as well as attracting various users.

The focus group expressed the importance of reconnecting Muharraq to the waterfront. According to [37] flexible designs that permit visibility to the surroundings or accessibility to unobstructed sight are valuable for the urban waterfronts. Regarding the organization of connections, as specified by the focus groups, the bridge's design should also promote visual references to the waterfront at Sa'ada Phase 1 site and to other landmarks of the area. This is especially important considering the valuable relationship between Muharraq and the seashore, as well as the historical city center, enhancing users' experience.

In support of the findings of the focus group discussions, the following criteria was determined from the SWOT analysis:

Impact on the Local Community

Sa'ada Phase 2 promotes the community spirit through accessibility, public spaces, and the spread of these streets that are currently so far apart. The project facilitates the connection of the old Muharraq and the new waterfront by creating physical infrastructure, enabling the inhabitants to be more involved with their environment. The provision of pedestrian walkways, the exposure of open public areas, and the improvement of the connection create favorable conditions for direct, social contact that forges the opportunity for a community sense of belonging in the city [38]. A series of research studies stated that pedestrian-friendly environments secure the growth of higher levels of social interaction, therefore enhancing the health of a community [39]. The project turns such ideas into design features by coordinating to have such areas that are more or less visited on a daily basis, becoming apparent in the construction of social capital, trust, and increased local identity, imperative for the long-term sustainability of the community.

Holding the most important architectural treasures and using them in today's-built environment, the new development not only guarantees the continuity of Muharraq's historical culture in the community but also ensures that the town, with its culture, is preserved. This attitude greatly facilitates the inhabitants in giving them a strong anchorage point. It is confident that, regardless of how the city expands to serve the needs of today, the people's self-image will not be altered. Jacobs speaks about the protection of the old and cultural properties as factors that keep the suburbs' identity; therefore, cities are where people are resettled and related to their historical background. Further, the two newest inquiries confirm this also, especially the one that indicates that cultural heritage could be a place-based identity and a citizenship community identity in building and resilience of sustainable cities [40].

Tourism and Economic Boost

The study done by [41] shows that the mixed-use benefits the local economy in terms of traffic patronage and the development of accessible public space. Unlike the first phase of Sa'ada, the second phase will involve giving instructions on the combination of commercial, residential, and art domains that are open together with the recreation of parks and gardens for both tourists and citizens.

On the other hand, the study indicates the threat that more people in residential areas are getting evicted because of high property values. [42] If not well handled, it would be a disastrous project that would tear apart the entire social fabric of Muharraq. The project desires a development that will protect people's needs and prevent the exploitation of big business companies. Local authorities should ensure that the project benefits everyone, not only outside investors and developers.

Mixed-Use Development and Sustainability

The Sa'ada Phase 2 project is a neighborhood where people live, shop, enjoy culture, and recreation [43]. By walking more and driving less, the project makes the city more sustainable [5]. Cities are made for people, not just for cars [44]. Studies show that walkable cities do better economically, and harmful emissions are less [45]. So, in Sa'ada Phase 2, walking connections promote lively shared spaces aiming for a sustainable city.

Social Equity and Inclusion

The challenge of the above scheme is that it directly assigns the economic gains for the more affluent societies as well as foreigners to the detriment of the local dwellers. The concept of 'renewal of cities, excluding the people in those cities, is supposed to be the needs of those people and not merely the needs of people who can make profits [5]. Therefore, the first measures that are going to be taken in order to eliminate this problem are the creation of new vacancies, for instance in the community, and the guaranteed activity of small businesses [46]. It is not simply about deciding and fulfilling their needs; that is what is needed to carry out a manual for a proper society. The new studies commend the role of the community in

implementing satisfaction of urban renewal projects, if inclusive rather than non-inclusive, suggesting that the planned process is just and thus efficient [47].

6. CONCLUSIONS

Sa'ada Phase 2 plays a crucial role in reconfiguring the old urban community of Muharraq with its waterfront, generating sociocultural benefits for Bahraini inhabitants and guests. In the role of a pedestrian bridge and plaza, this project aims at the literal and symbolic bridge between the old town and the modern leisure services area. The discussions in this study have revealed some valuable information in relation to the specific design necessities and challenges of this study, as well as stressing the part played by environmental, functional, and cultural elements to enhance the connectivity within cities. The ideas mentioned in the focus group discussions show that certain design features are needed to accommodate the specific character of Muharraq heritage, and at the same time, meet the practical requirements of making the space pedestrian-friendly. The peculiarities of the subject combine the ideas of the design of the pedestrian bridge and plaza that should fit Muharraq's identity, which means the use of local materials, forms, and styles to represent the city's history, to be in line with the latest guidelines for the development of Muharraq city [48]. This goal ensures that, apart from meeting the aesthetic concerns of the community, the project is aligned with the community's values and history. Moreover, the input received from the members revealed that accessibility was an important factor. This means integrating a design that will be functional for users of all categories, including children, families with elderly people, people with impairments, visitors, and the elderly. This factor can be regarded as critical for enhancing the use of space and supporting its role as a community meeting point.

The challenge of integrating contemporary design into a historically significant area is highlighted in this study. Making sure the plaza and bridge blend in with the traditional urban fabric without dominating it or detracting from its distinctive character is one of the primary concerns with spatial integration. Other topics that were highlighted include traffic management and pedestrian crossing, since Sa'ada Phase 1 is separated from Phase 2 by a highway. It is mandatory to design the bridge to allow safe pedestrian movement. Besides, the traffic should consider crossing the roads from Muharraq city to the intended site safely and efficiently. That is to say, achieving these elements involves using the proper and innovative measures in the layout and circulation, which pertain to vehicles and pedestrians.

The design features considering the environmental issues suggested by the focus group participants are also aligned with the current and future trends of sustainable city development. Thus, the suggestions given here may be considered not only as a contribution to the project's future sustainability but also as a contribution to further urban sustainability.

The SWOT analysis from this study also identifies some problems and challenges associated with the project. However, the general argument that Sa'ada Phase 2 has proved successful on different parameters cannot disregard specific threats – it risks getting either gentrified or over-commercialized. If the numerous masses of tourists and commercial areas are not managed efficiently the local communities may be obliterated or the historical space replaced with something obscene. Critic environmental and infrastructure requirements must be added to this, particularly the construction of the connection to the waterfront on the opposite side of the primary street, which raises the question of the feasibility of this venture in the long term. Hence, precaution by monitoring and altering the plan is essential so that the project is well-analyzed concerning the economy, Social impact, and culture.

The limitation of this present research is that the focus group is very much dependent on the participants' views on a specific subject, which may be biased. It simply means that participants may post only self-considerations or encounters that may not reflect the community. This can be supported by the survey findings besides the observational studies that validate the focus group response. Despite the logical

recommendation offered by the research, budget constraints, technical difficulties, or the conflicting interests of other stakeholders such as developers and other regulating agencies make implementation somewhat difficult.

Using these findings together with related literature, one is able to develop a clear model of how the Sa'ada Phase 2 can be adjusted to address both functional and cultural requirements. Essential techniques that could be employed include evaluating other culturally sensitive and waterfront projects to understand how the design of the pedestrian bridge and plaza can be further enhanced to allow reflection and incorporation of heritage onto it, how the design can be made more friendly for users of diverse abilities, how safety can be improved and how the design can best encourage public participation. Implementing these solutions might not only respond to the challenges expressed by the focus group participants but also guarantee that the designed space will be meaningful to the community, leaving a long-lasting, memorable impact by providing continuity to the relationship of Muharraq with its waterfront. By reconnecting the old city to the waterfront and enhancing the public spaces, the project not only helps in the internal growth of the local people and the deepening of the community connection, but also is the most significant stimulus that is implemented by tourism and local commerce [49].

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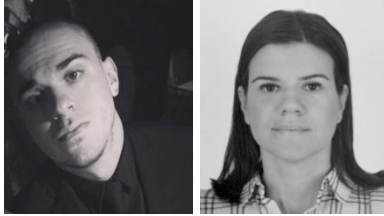
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Virtual Reality Learning Environments In Architecture And Design Education: A Bibliometric Review



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Abstract: Virtual Reality (VR) technologies are increasingly being utilized in the fields of architecture and design education due to their potential to supporting creating interactive, immersive learning environments. This paper provides a bibliometric review of 68 academic studies between 2000 and 2025 that discuss the use of VR tools, platforms, and games in learning environments. The research aims to find trends, gaps in research, and thematic trends in the application of VR technologies in design education. The findings indicate a growing interest in integrating VR technologies into architectural education worldwide. Architectural design emerges as the most researched topic, highlighting VR's significant potential in supporting design-related activities, visualization, and collaborative learning. Besides design-oriented research, VR applications have also been researched in fields like construction education, architectural history, and landscape architecture. The paper categorizes the reviewed works into three broad categories of VR uses: tools and applications, platforms, and game-based learning environments. Among these, tools and applications are the most prevalent, typically developed to address specific educational needs, while game-based approaches remain less explored, despite their potential to enhance engagement through interactive, game-like settings. While the bibliometric analysis highlights the educational benefits of VR—such as enhanced visualization, interactivity, and increased student motivation—it also identifies key challenges. These include the need for more empirical evidence on long-term learning outcomes and the development of standardized and pedagogical models for effective VR integration. The paper concludes by emphasizing the importance of future research in addressing these gaps to support the evidence-based implementation of VR technologies in architectural and design education.

Keywords: Virtual Reality, Architectural Education, Design Education, VR Applications, Immersive Learning, Bibliometric Analysis

Mimarlık ve Tasarım Eğitiminde Sanal Gerçeklik Öğrenme Ortamları: Bibliyometrik Analiz

Özet: Sanal Gerçeklik teknolojileri, etkileşimli ve sürükleyici öğrenme ortamları oluşturma potansiyelleri nedeniyle mimarlık ve tasarım eğitiminde giderek daha fazla kullanılmaktadır. Bu makale, öğrenme ortamlarında VR araçlarının, platformlarının ve oyunlarının kullanımını inceleyen ve 2000-2025 yılları arasındaki 68 akademik çalışmayı kapsayan bibliyometrik bir analiz sunmaktadır. Araştırma, tasarım eğitiminde VR teknolojilerinin uygulanmasındaki eğilimleri, araştırmalardaki eksiklikleri ve tematik eğilimleri bulmayı amaçlamaktadır. Bulgular, dünya genelinde mimarlık eğitimine VR teknolojilerinin entegrasyonuna yönelik artan bir ilgi olduğunu göstermektedir. Mimari tasarım, en çok araştırılan konu olarak öne çıkmakta olup, VR'nin tasarım odaklı faaliyetleri destekleme, görselleştirme ve işbirlikçi öğrenme konularındaki büyük potansiyelini vurgulamaktadır. Tasarım odaklı araştırmaların yanı sıra, sanal gerçeklik uygulamaları yapı eğitimi, mimarlık tarihi ve peyzaj mimarlığı gibi alanlarda da incelenmiştir. Makale, incelenen çalışmaları üç geniş VR kategorisine ayırmaktadır: araçlar ve uygulamalar, platformlar ve oyun tabanlı öğrenme ortamları. Bunlar arasında, genellikle belirli eğitim ihtiyaçlarını karşılamak amacıyla geliştirilen araçlar ve uygulamalar en yaygın olanıdır. Öte yandan, etkileşimli ve oyun benzeri ortamlar aracılığıyla öğrenci katılımını artırma potansiyeline sahip olmasına rağmen, oyun tabanlı yaklaşımlar daha az araştırılmıştır. Bibliyometrik analiz, VR'nin eğitimde sağladığı görselleştirme, etkileşim ve öğrenci motivasyonunu artırma gibi faydalarını vurgularken, bazı önemli zorluklara da dikkat çekmektedir. Bu zorluklar arasında, uzun vadeli öğrenme çıktılarına ilişkin daha fazla ampirik kanıt ihtiyacı ve VR'nin etkili bir şekilde entegrasyonu için standartlaştırılmış ve pedagojik açıdan uygun modellerin geliştirilmesi yer almaktadır. Makalenin sonuç bölümü, bu eksikliklerin giderilmesine yönelik gelecekteki araştırmaların önemini vurgulayarak, VR teknolojilerinin mimarlık ve tasarım eğitiminde kanıta dayalı uygulanmasını desteklemeyi amaçlamaktadır.

Anahtar kelimeler: Sanal Gerçeklik, Mimarlık Eğitimi, Tasarım Eğitimi, VR Uygulamaları, Sürükleyici Öğrenme, Bibliyometrik Analiz.

1. INTRODUCTION

Architecture and design education is faced with a paradigmatic shift triggered by rapid progress in digital technology. Use of digital tools and methods has transformed architectural practice, promoting innovations such as parametric design, algorithmic processes, and simulated visualization practices [1,2]. But the pace of this technological advancement has raised questions regarding the efficiency and pedagogical appropriateness of novel tools in comparison to traditional pedagogic methods [3]. As the architectural profession adopts more advanced digital technologies, including automation, data-driven design processes, and virtual spaces [4], universities have been behind, creating a gap between curricula in teaching and professional practice [5,6]. This gap calls for a strategic transformation of architecture and design education to meet the demands of a more digital and networked professional sphere.

Traditionally, architecture and design education have revolved around studio-based education with emphasis on sketching, model making, and theoretical knowledge [7]. These traditional approaches have provided students with a solid foundation in design, spatial perception, and critical reasoning [8]. With the architectural practice moving towards computationally-driven workflows [1], challenges still persist regarding the efficiency of traditional pedagogical practices [9]. The evolution of parametric and data-driven design processes has profoundly influenced professional practice because software like Building Information Modeling (BIM) and computational design tools became common industry software [10]. But while this has transformed practice, it has historically been challenging for education programs to successfully integrate these technologies into the studio-based pedagogical model, thereby creating a gap in skills lowering students' preparedness for practice in today's era [11,12]. The adoption of Virtual Reality (VR) technologies in architecture and design education has tremendous potential for bridging this gap. VR enables immersive, interactive, and spatially accurate learning environments that go beyond the limitations of traditional 2D presentations [13]. With VR, students can virtually move through building spaces dynamically and experience scale, proportion, and spatial relationships directly rather than through symbolic visualization [14]. Current research has indicated that VR applications are suitable for experiential and situated learning, which facilitates a more intuitive understanding of architectural principles and design strategies [6,15]. Apart from enhancing spatial cognition, VR-based design environments facilitate real-time collaboration, through which students can work with fellow students and instructors regardless of geographical location [16].

With the growing interest in VR as an educational tool, there is a need for a systematic review of its application in architectural education to determine what is being done, where research is headed, and implementation challenges. This research aims to conduct a bibliometric review of academic publications from 2000-2025, with specific focus on the development and pedagogical integration of VR technologies in architecture and design education. Using the content analysis of publication trends, themes, and co-authorship networks, the paper strives to provide insight into the trend of adoption of VR in architectural education curricula. The study further aims to acknowledge the existing literatures and sketch out directions for future work that will further encourage effective and sustainable adoption of VR technologies into architecture education. Through this bibliometric overview, the paper contributes to the ongoing debate regarding digital transformation in architecture and offers a framework for aligning educational practice with the evolving needs of the profession and the new world shaped by technology.

2. METHOD

This paper follows the bibliometric review methodology in order to explore the role of virtual reality in architecture education. This method allows for an effective and structured analysis of existing literature, which helps to identify major trends, benefits, and challenges concerning Virtual Reality in the field of

architecture and design. This method is valued for its ability to synthesize and critically evaluate multiple studies in a specific field, thereby ensuring the reliability and validity of results [36].

Relevant studies were found from databases like Scopus, Web of Science, IEEE Xplore, ScienceDirect, and Google Scholar. English and Turkish key words were the part of strategy in order to catch wide extent information. Examples include "virtual reality in architectural education," "VR in design education", "game-based learning and architecture," "design and construction training by using VR games," and "immersive learning in architecture." such that Turkish-language studies may not be missed, keywords in Turkish, such as "mimarlık eğitiminde sanal gerçeklik," "oyun tabanlı öğrenme ve mimarlık," and "iç mimarlık eğitiminde VR," were also used.

Reference lists in the first set of retrieved papers were further searched to broaden this review, thus finding even more relevant material. The iteration served to facilitate thorough review for known and less-known but relevant studies on the subject. Combination database searches using sophistication, along with manual tracking references and using a set of keywords in different languages, ensured comprehensive and inclusive assessment of literature was achieved. In fact, the review has been dominated by peer-reviewed journal articles, conference proceedings, and book chapters, published from 2000 through 2025, with research on the use of virtual reality in architectural education, consequently impacting educational outcomes. Each identified paper was rated using predefined categories such as research objectives, methodology, number of participants, experimental design, technological infrastructure used, and pedagogical outcomes. A thematic analysis was done to identify recurrent themes, directions, and gaps within the literature. The comparative approach was conducted to test different methodologies using VR in architecture education contexts.

The selection of the papers relevant for this review, in relation to architectural and interior architecture education, gave a clear emphasis. Consistent with the primary purpose of the research in terms of uncovering VR-based learning environments specific to architecture and design, research from related fields such as industrial design was excluded. Also, the fact that there was a study of educational usage and not a professional or client-based project dictated that only an academic work already implemented in the university environment is included.

The citation count was also taken into consideration in order to include most referenced and significant research in the field and to further fine-tune the selection process. This strategy ascertained that the review encompassed major contributions and widely acknowledged development. The application of ResearchRabbit or related artificial intelligence algorithms for finding and ranking high-impact papers allowed a more comprehensive and efficient reviewing process. These criteria are used to emphasize the most important and relevant VR research in architectural and interior architecture education.

3. LITERATURE REVIEW

The literature review section of this study provides a comprehensive overview of existing research on Virtual Reality in architecture and design education, guided by bibliometric methods. It initially introduces bibliometric analysis as a systematic approach to map the structure and research trends in educational environments, highlighting its applicability and methodological foundations. The review thus offers a profile of VR technology and pedagogical uses within architecture and design education and historicizes the evolution over time as it focuses on how revolutionary such have proved to be in respect to studio teaching and learning practices. Subsequently, a methodology for categorizing VR learning methods is demonstrated that distinguishes three quite dissimilar types namely platforms, tools/applications and games providing very different kinds of educational purpose, with extremely disparate models for deployment.

Next, the key research themes in the reviewed literature are discussed, including immersive design studios, collaborative virtual environments, game-based learning, and simulation-based training. Finally, the review describes the existing gaps in research, pedagogical and technological challenges, and future research avenues for further studies on VR integration in architectural education.

Bibliometric Review in Academic Research

Bibliometric analysis is a technique that is in being used in academic fields for the systematic investigation of the structure, development, and trends within a particular topic. Bibliometric review is an invaluable asset in the context of education research to study patterns of publication, research cooperation, theme development, and contribution of academic work [17]. It enables researchers to identify emerging trends, assess the evolution of areas of research, and identify research gaps by quantitatively studying bibliographic data like references, co-authorship, citations, and keywords [18]. Not only does this systematic approach reveal the past history of a field of research, but also signals upcoming directions in research by uncovering untapped areas. Several approaches are commonly employed in bibliometric studies to study research productivity are:

1. **Citation Analysis:** Citation analysis examines the frequency with which a publication is cited, providing an indication of the impact and reach of specific studies, authors, or journals [19]. In education research, frequently cited publications are often seminal theory or methodological advances.
2. **Co-Authorship Analysis:** Co-authorship analysis examines collaboration patterns in research by analyzing author, institution, and country linkages. The technique is employed to identify research networks and collaboration trends in a specific area of study [20].
3. **Keyword Co-Occurrence Analysis:** By analyzing the occurrence of keywords together in publications, researchers are able to map the conceptual landscape of a field and identify advancing or receding topics [21].
4. **Co-Citation Analysis:** Co-citation analysis measures the extent to which two documents are co-cited, providing data on the intellectual structure of the field [22]. This technique is highly suitable for obtaining core literature and theoretical foundations, and for determining paradigm shifts over time.

Overview of Virtual Reality and Its Utilization in Architecture and Design Education

Virtual reality have been extensively utilized across several educational fields, such as medical training, engineering, and architecture, owing to their capacity to replicate real-world experiences and intricate problem-solving situations [6]. Researchs indicates that virtual reality enhances spatial cognition, problem-solving abilities, and collaborative learning, rendering it a valuable instrument for design-oriented fields like architecture [23]. In the realm of architectural and design education, the integration of VR has helped enhance spatial understanding, improve design comprehension, and create immersive learning experiences. Unlike traditional two-dimensional representations, VR lets students interact with design models intuitively and immersively to engage more profoundly with spatial configurations and scale [24]. Studies have shown that VR-based environments significantly help students develop a more accurate perception of spatial relationships, an important aspect of architectural design [25]. Thus, a key advantage of VR in design education is its capacity to enhance spatial cognition and improve visualization skills.



Figure 1. VR application of virtual exhibition of Bahcesehir University Faculty of Architecture and Design (Author's archive)

While the educational potential of VR and related immersive technologies is considerable, their advantages and limitations need to be balanced. As for its advantages; VR allows for the navigation of three-dimensional architectural environments, helping students better understand spatial relationships and design principles compared to conventional 2D drawings [14]. VR enables experiential learning through real-time interaction with design components, which is consistent with constructivist pedagogical principles [13]. Collaborative VR spaces, such as The Wild and Mozilla Hubs, allow real-time interaction among students and instructors regardless of geographical location, encouraging collaboration and communication [16]. VR construction simulations, such as those used in safety training modules, allow students to practice complex or hazardous activities without risks [6]. As an example seen in Figure 1, integrating VR into the exhibition system, Bahçeşehir University verifies the potential of immersive technologies in expanding audience reach. The VR platform allows members of the public to experience virtual exhibitions in a manner as if they were present in a physical gallery, enabling a more personal and experiential understanding of the works on display.

When challenges and limitations of VR in architectural education thought; long-term exposure to VR can lead to motion sickness, confusion, and cognitive overload, particularly when moving through complex or highly dynamic spaces [26]. Acquisition and maintenance of VR hardware and software and technical expertise for their implementation are barriers for the majority of universities [6]. Teachers find it challenging to integrate traditional teaching practices into VR-based education, emphasizing the need for teacher training and curriculum materials [27]. VR environments, particularly game-based learning platforms, can be more entertainment-driven than education-centric at times, rendering learning exercises less profound and demanding [28].

Categorization of VR Learning Environments: Platforms, Applications/Tools and Games

Typology of Virtual Reality learning environments is needed to understand the different ways in which this technology is being applied in architecture and design education. VR for learning purposes vary significantly in function, intent, and technological infrastructure. To provide an organized understanding of such uses, this study categorizes VR learning environments into three broad categories: platforms, applications/tools, and games. This three-fold classification enables examination of the educational potential of VR by delineating the foundational systems that support VR experiences, the computer programs that allow design and learning activities, and the game-based environments that create interactive worlds for experience. The proposed categorization is based on existing studies of educational VR methods. Previous research has employed similar categorizations, usually based on pedagogical aims or technological features [29,30]. For instance, Zhao et al. [31] categorize VR applications based on content

delivery modes, and Radianti et al. [6] identify application domains based on learning goals. In this paper, the three categories are described in detail and their relevance to architectural and design education is explored.

VR Platforms

VR platforms are the foundational infrastructure for developing, deploying, and managing immersive experiences. VR platforms include both software development environments and hardware ecosystems, providing the technical underpinning for VR applications. Anthes et al. [32] explain that VR platforms are typically categorized into three types: desktop-based, mobile-based, and head-mounted display (HMD)-based systems.

1. **Desktop-Based VR Platforms:** Desktop-based VR platforms, such as Unity3D, Unreal Engine and Twinmotion, allow for the creation of virtual environments that are accessed through an interface on a computer. They are being utilised in architect and design education heavily for tasks such as 3D modeling and virtual walk-throughs.
2. **Mobile-Based VR Platforms:** Mobile-based systems, such as Google Cardboard and Oculus Go, offer low-cost and accessible VR experiences through the use of smartphone technology [6]. These types of systems are particularly useful in introductory-level courses and for individual, self-paced learning activities.
3. **HMD-Based VR Platforms:** HMD-based systems like Oculus Rift, HTC Vive, and Microsoft HoloLens provide fully immersive environments with real-time spatial interaction [26].

VR Applications/Tools

VR applications/tools are the software programs that are specifically designed to support learning activities, e.g., design modeling, collaboration, and performance analysis. Unlike platforms, which provide the infrastructure for VR development, applications/tools provide user-friendly interfaces for direct learning interaction. According to Mikropoulos and Natsis [27], VR learning tools can be categorized according to their pedagogical function, i.e., tools for exploration, simulation, collaboration, and design creation.

1. **Exploration Tools:** Google Earth VR and Wander are a few of the tools that enable students to explore architectural spaces and urban settings in a virtual manner. These tools are particularly helpful to instruct site analysis and environmental context.
2. **Simulation Tools:** Simulation software, like VR Safety Training environments, replicates actual construction settings to teach procedural knowledge and safety protocols. In architectural education, these tools assist in making students understand structural behavior and material interaction.
3. **Collaborative Tools:** Collaborative VR tools, such as The Wild and Mozilla Hubs, facilitate real-time interaction among the students and the tutors from distant locations [16].
4. **Design Creation Tools:** There are some tools like VR Sketch and SketchUp VR, which are aimed at architectural design tasks, allowing students to manipulate, work with, and analyze virtual buildings within immersive environments [33].

VR Games and Game-based Learning Environments

Game-based learning environments (GBLEs) in VR adopt the gamification concepts to implement interactive and captivating learning experiences. The application of game mechanics such as challenges, rewards, and narratives can indeed enhance motivation, engagement, and knowledge retention for architecture and design education [28].

1. **Serious Games for Architectural Education:** Serious educational games such as Virtual Construction Site and ArchiVR are specifically designed to educate in architectural concepts and

construction operations [34]. The games typically come with real-world construction settings in which the students can rehearse design elements and learn construction plans.

2. **Simulation-Based Games:** Simulation games provide interactive learning experiences in structural integrity, material performance, and energy efficiency. For instance, ConstructSim VR simulates building element structural performance in different environmental loads [35].
3. **Design Games:** Games like Minecraft Education Edition allow students to engage in open-ended design projects as they construct and develop their problem-solving and collaborative abilities. These spaces allow for the exploration of design ideas in a game-like yet learning-conducive setting.

Key Research Themes in VR-based Architectural Education

Uses of Virtual Reality to architecture and design education have yielded a conflicted research foundation, with authors looking at the application to enable learning of spatiality, exploration of design, and group work. The dominant themes that emanate from the literature are identified in the subsequent section, pinpointing the priority areas of concern and their impact on pedagogic practice. One of the most important research areas is spatial understanding and visualization. The nature of immersion in VR allows architecture students to walk around and explore design concepts at full size, which has been proven to increase spatial understanding and design comprehension [13]. Studies have revealed that VR software can allow students to better comprehend complex spatial relationships than 2D drawings, particularly when exploring volumetric, material, and structural aspects of architectural forms [14].

Another significant theme is the use of VR for collaborative learning and design. With professional practice increasingly based on interdisciplinary teamwork, scholars have explored how VR collaborative environments can simulate professional design processes. Programs like The Wild and Mozilla Hubs support synchronous, offsite collaboration, with students co-designing and inspecting designs simultaneously [16]. These studies hint at the capability of VR to augment collaboration, communication abilities, and joint decision-making.

Game-based learning is also a prominent topic in VR architectural education. Borrowing from the concepts of gamification, research has explored how VR games could increase motivation and engagement by using challenges, rewards, and interactive tasks [28]. Minecraft Education Edition, for example, has been used in education for design principles in a gamified but pedagogical setting with positive outcomes for creativity, problem-solving, and collaboration.

Another field that is of great interest is simulation-based training. VR applications which simulate construction works, material behaviors, and safety protocols have grown in popularity across architecture and construction education [6]. Through these applications, students are able to practice the real tasks like site visits or structural inspections, and gain clear understanding of how construction works but without the limitation of physical field visits. Collectively, these research themes point to VR's potential for augmenting architectural education in terms of interactive, collaborative, and immersive learning processes.

Gaps, Challenges, and Future Directions for VR in Architecture and Design Education

Despite the rising applications of Virtual Reality technologies in architecture and design education, several gaps and issues remain that need to be explored and innovated further. While earlier studies have determined the potential of VR in education for enhancing spatial knowledge, experimenting with design, and collaborative learning, their application in teaching practice remains uneven and fragmented [6]. This section of the chapter outlines the principal limitations in the literature, the challenges of using VR, and some potential areas for future studies.

One of the areas that are lacking in current research is longitudinal studies assessing the long-term educational impacts of VR-based learning environments [6,13]. Most of the current research is focused on

short-term effects, such as immediate performance improvement or self-reported interest, without evaluating if these experiences translate to long-term effects on knowledge retention, design thinking, or the acquisition of spatial abilities. Longitudinal study designs must be employed in future research to evaluate such long-term effects, particularly in architectural design education, where professional practice is highly dependent on spatial cognition.

A second important gap is the lack of empirical research on pedagogical methods that effectively integrate VR into architecture education. While studies like Wang et al. [15] and Milovanovic et al. [14] have examined the affordances of VR environments, few have provided concrete, evidence-based suggestions for educators who wish to incorporate these technologies into studio-based design courses. Lack of pedagogic models or framework makes it tough for academic institutions to embrace VR solutions. Upcoming research efforts must endeavor to conceptualize and empirically validate pedagogically strong models bridging VR applications to well-documented education principles like constructivism and experiential learning.

Limitations from a technical front too pose severe hindrances towards adoption of VR into architecture and design education. Hardware constraint, such as the cost of VR headsets and computational power required for rendering complex architectural models, continues to constrain adoption [32]. In addition, motion sickness, resolution of display, and interaction fidelity problems can reduce effectiveness of VR learning environments, particularly for high precision spatial manipulation tasks [26]. Advances in VR hardware, like the manufacture of less expensive, wireless, and high-definition units, are required to overcome these challenges and render VR more affordable for financially strained schools.

Pedagogical concerns extend beyond hardware and software problems. Teachers typically face a steep learning curve in using VR technology because it requires technical proficiency for design programs as well as for immersive hardware [27]. Lack of proper professional development support and instructional resources exacerbates this issue, resulting in patchy or tangential applications of VR throughout the classroom. In order to address this challenge, future research will have to focus on the development of training programs, better practice guidelines, and easy-to-use interfaces that prepare teachers to use VR in education successfully.

Ethical and psychological implications must also be probed more. Prolonged exposure to deeply immersive VR environments has been associated with symptoms of disorientation, motion sickness, and skewed perceptions of reality [26]. In educational settings, these effects could impact students' health, motivation, and performance. Moreover, the increasing use of VR creates concerns regarding data privacy, especially when applications collect behavioral data for performance assessment. Future research should address these ethical issues by creating guidelines and safeguards that preserve students' privacy while ensuring guarantees for the safe and ethical use of immersive technologies in education.

In summary, while VR has demonstrated tremendous promise in enhancing architectural and design education, gaps and challenges are significant. Addressing these requires interdisciplinary research studies, technological advancements, pedagogical innovation, and ethical concerns. Longitudinal impacts, pedagogical paradigms, platform interoperability, teacher training, game-based learning, and ethical safeguards must be the subjects of future studies to maximize the educational value of VR technologies and support the next generation of designers and architects.

4. FINDINGS

In summary, this review are based on 68 academic studies on the role of virtual reality concepts in architecture and design education. These academic researches has been selected from years between 2000-

2025. Selected studies are presented in Table 1 and are arranged chronologically according to their publication years.

Table 1. Selected studies

#	Title	Authors	Year
1	An immersive virtual reality learning system for building systems in architectural design education	Natephra, W., Shahinmoghdam, M., & Motamedi, A.	2025
2	A 3D quick sketch algorithm in virtual reality for concept design in architectural studio	Erdem, E., & Çiftçiöğlu, Ö.	2024
3	A Comparative Study on the VR Experience of Students in a Digital Documentary Game	Şahin, P., Çalışkan, A., Hacıtahiroğulları, Z. V., Ceylan, S., Çatak, G., & Masalci, S. Z.	2024
4	Co-Created Virtual Reality (VR) Modules in Landscape Architecture Education: A Mixed Methods Study Investigating the Pedagogical Effectiveness of VR	Andalib, S. Y., & Monsur, M.	2024
5	Design of Interactive Walkthrough System of Huizhou Style Architecture Based on 3D and VR Technology	Wang, Huasheng & Qiu, Duorong & Li, Weimin & Li, Weiwei & Wu, Zeyang.	2024
6	Enhancing Online Learning in Architectural Education: A Virtual Reality Enabled Experiment with Arkio	Yıldırım, E.	2024
7	Mimarlık Öğrencilerinin Sanal Gerçeklik Ortamında Safranbolu Tabakhanesinde Rölevo Alma Deneyimi	Küçükkara, M. Y., Özacar, K., & Ortakçı, Y.	2024
8	On the application of virtual reality technology in the teaching of "landscape architecture design"	Yu, A., & Xu, Z.	2024
9	Project Beyond: An Escape Room Game in Virtual Reality to Teach Building Energy Simulations	Arbesser-Rastburg, G., Safikhani, S., Gustin, M., Hopfe, C., Schweiger, G., & Pirker, J.	2024
10	Research on the Application of Three-Dimensional Virtual Reality Technology in Landscape Architecture Design	Chen, Y.	2024
11	A Proposed Framework for integrating IVR Technology in Architectural Design courses; Application on architectural schools in Egypt	Abdelhameed, W. A.	2023
12	BIM-enabled virtual reality (VR)-based pedagogical framework in architectural design studios	Rasouli, A. H., Banihashemi, S., Sanders, P., & Rahimian, F. P.	2023
13	Design with Sound: The Relevance of Sound in VR as an Immersive Design Tool for Landscape Architecture	Luoma, L., Fricker, P., & Schlecht, S. J.	2023
14	Immersive Virtual Reality, Tool for Accessible Design: Perceived Usability in an Interior Design Studio Setting	Santos, R. M., & Duarte, J. P.	2023
15	Integrating Virtual Reality and interactive game for learning structures in architecture: the case of ancient Chinese dougong cognition	Pei, W., Lo, T.T.S., & Guo, X.	2023
16	Mimarlıkta Yapı Dersleri Müfredatı Dijital Dönüşüm Modeli	Seyman Güray, T., & Kısmet, B.	2023
17	Virtual Reality Technology in Architectural Theory Learning: An Experiment on the Module of History of Architecture	Shanti, Z., & Al-Tarazi, D.	2023
18	VRArchEducation: Redesigning building survey process in architectural education using collaborative virtual reality	Özacar, K., Ortakçı, Y., & Küçükkara, M. Y.	2023
19	A workflow for multi-user VR application within the physical classrooms of architecture and urbanism courses	Gomes, Emerson Bruno & Rebelo, Francisco & Vilas Boas, Naylor & Noriega, Paulo & Vilar, Elisângela.	2022
20	BIM LOD + Virtual Reality -- Using Game Engine for Visualization in Architectural & Construction Education	Anifowose, H., Yan, W., & Dixit, M.	2022
21	Building a virtual Roman city: teaching history through video game design	Forsyth, H.	2022
22	Dreamscape Bricks VR: An Experimental Virtual Reality Tool for Architectural Design	Doma, O. O., & Şener, S. M.	2022
23	Introducing Immersive Virtual Reality in the Initial Phases of the Design Process—Case Study: Freshmen Designing Ephemeral Architecture	González, M. A., & Blanco, A.	2022
24	The Application of Virtual Reality Technology in Interior Design Education: A Case Study Exploring Learner Acceptance	C. Li and G. Xie	2022

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25	The potential of immersive virtual reality for representations in design education	Horvat, N., Martinec, T., Lukačević, F. et al.	2022
26	Applying immersive virtual reality for remote teaching architectural history	Chan, C.-S.	2021
27	Embedding VRAD (Virtual Reality Aided Design) in Architectural Pedagogy	Alizadehsalehi, S., & Yitmen, I.	2021
28	FAMU Digital Documentation, a VR narrative for architectural education	Lescop, L., Chin, A., Park, S. B., Ehtemami, A., & Bernardin, S.	2021
29	Integrating virtual reality technology into architecture education: the case of architectural history courses	Ibrahim, A., Al-Rababah, A. I., & Bani Baker, Q.	2021
30	Mixed Assessment of Virtual Serious Games Applied in Architectural and Urban Design Education	Fonseca, D., Cavalcanti, J., Peña, E., Valls, V., Sanchez-Sepúlveda, M., Moreira, F., Navarro, I., & Redondo, E.	2021
31	SimYA: A virtual reality-based construction studio simulator	Şahbaz, E.	2021
32	Strategies for the Utilization of Virtual Reality Technologies in the First Year of Architectural Education	Ceylan, S	2021
33	The Drawing and Perception of Architectural Spaces through Immersive Virtual Reality	Gómez-Tone, H. C., Bustamante Escapa, J., Bustamante Escapa, P., & Martin-Gutierrez, J.	2021
34	The effectiveness of interactive virtual reality for furniture, fixture and equipment design communication: an empirical study	Prabhakaran, Abhinesh & Mahamadu, Abdul-Majeed & Mahdjoubi, Lamine & Manu, Patrick & Che Ibrahim, Che Khairil Izam & Aigbavboa, Clinton	2021
35	Developing an Integrated VR Infrastructure in Architectural Design Education	Aydin, S., & Aktaş, B.	2020
36	Immersive Virtual Reality for Assisting in Inclusive Architectural Design	Lach, E., Benek, I., Zalewski, K., Skurowski, P., Kocur, A., Kotula, A., Macura, M., Pamuła, Z., Stankiewicz, M., & Wyrobek, T.	2020
37	Implementing Virtual Reality Headsets in Design Education	Chan, C. P.	2020
38	The Influence of Virtual Reality on Design Process Creativity in Basic Design Education	Obeid, S., & Demirkan, H.	2020
39	User Study on Virtual Reality for Design Reviews in Architecture	Zaker, R., & Coloma, E.	2020
40	Using Virtual Reality to Improve Visual Recognition Skills of First Year Architecture Students: A Comparative Study	Ceylan, S., Şahin, P., Seçmen, S., & Süher, H. K.	2020
41	Vr-Based Interactive Learning In Architectural Education: A Case On Safranbolu Historical Bathhouse	Şahbaz, E.	2020
42	A New Game-Based Immersive Virtual Learning Tool For Perceiving Behaviour Of Structures: Structurepuzzlevr	Güney, E.	2019
43	CubeVR: Digital Affordances for Architecture Undergraduate Education using Virtual Reality	Goulding, J., Rahimian, F. P., & Wang, X.	2019
44	Design and Development of a Virtual Reality Educational Game for Architectural and Construction Reviews	Castronovo, Fadi & Nikolic, Dragana & Mastrolembo Ventura, Silvia & Akhavian, Reza & Gaedicke, Cristian & Yilmaz, Semih.	2019
45	Integration of Virtual Reality (VR) in Architectural Design Education: Exploring Student Experience	Williams, J., Orooji, F., & Aly, S.	2019
46	The application of virtual reality technology in architectural pedagogy for building constructions	Al-Rawabdeh, W., & Al-Azhari, W.	2019
47	Thinking in Virtual Spaces: Impacts of Virtual Reality on the Undergraduate Interior Design Process	Pober, E. & Cook, M.	2019
48	Usability of virtual reality for basic design education: a comparative study with paper-based design	Özgen, D. S., Afacan, Y., & Sürer, E.	2019
49	Usability studies on building early stage architectural models in virtual reality	de Klerk, R., Mendes Duarte, A., Pires Medeiros, D., Pinto Duarte, J., Jorge, J., & Simões Lopes, D.	2019
50	User-centered interior finishing material selection: An immersive virtual reality-based interactive approach	Zhang, Y., Liu, H., Zhao, M., & Al-Hussein, M.	2019
51	An Educational Application Based on Virtual Reality Technology for Learning Architectural Details: Challenges and Benefits	Maghool, S. A. H., Moeini, S. H. I., & Arefazar,	2018
52	Implementing and Evaluating an Immersive Virtual Learning Environment for Learning How to Design in Human-Scale	Sönmez, O.	2018

53	Immersive environment for improving the understanding of architectural 3D models: Comparing user spatial perception between immersive and traditional virtual reality systems	Paes, D., Arantes, E., & Irizarry, J.	2017
54	Integrating Procedural Modelling Process and Immersive VR Environment for Architectural Design Education	Lin, C.-H., & Wang, Y.-C.	2017
55	Investigating the Effect of Employing Immersive Virtual Environment on Enhancing Spatial Perception within Design Process	Abu Alatta, R. T., & Freewan, A. A.	2017
56	Sanal gerçekliğin iç mimarlık eğitime etkisi	Şekerçi, C.	2017
57	Development of High-Definition Virtual Reality for Historical Architectural and Urban Digital Reconstruction: A Case Study of Azuchi Castle and Old Castle Town in 1581	Fukuda, T., Ban, H., Yagi, K., & Nishiie, J.	2015
58	Rediscovering Virtual Reality in the Education of Architectural Design: The immersive simulation of spatial experiences	Angulo, A.	2015
59	Heritage conservation and architectural education: “An educational methodology for design studios”	Elkadi, H.	2014
60	Virtual Reality Use in Architectural Design Studios: A Case of Studying Structure and Construction	Abdelhameed, W. A.	2013
61	An affordable immersive environment in beginning design studio education.	Gundrum, J.	2012
62	Development of Virtual Reality Tool for Creative Learning in Architectural Education	Kamath, R. S., Dongale, T. D., & Kamat, R. K.	2012
63	Digital preservation of historical buildings using virtual reality technologies	Hrozek, F., Sobota, B., & Szabó, C.	2012
64	Evaluating Relative Impact of Virtual Reality System Variables on Architectural Design Comprehension and Presence	Kalisperis, L. N., Muramoto, K., Balakrishnan, B., & Zikic, N.	2006
65	Boosting up Architectural Design Education with Virtual Reality	Dvorak, J., Hamata, V., Skacilik, J., & Benes, B.	2005
66	Integrated architectural surveying and planning: Methods and tools for recording and adjusting building survey data	Boeykens, S., Neuckermans, H., & Neuckermans, H.	2005
67	Virtual Reality in the Design Studio: the Eindhoven Perspective	Verbeke, J., & Vanhoutte, T.	2002
68	The representation of virtual reality in education	Antonietti, A., Rasi, C., Imperio, E., & Sacco, M.	2000

The studies listed in Table 1 illustrate the gradual integration of virtual reality technologies into educational contexts within architectural studies. Research developed over time is distributed with a view to providing an accurate picture of what happened regarding developments in the use of this technology. The trend of temporal publications allows the scientific world to increase interest in this area of VR learning and take part in discussion of the role that this new paradigm assumes. The following table shows the chronological distribution of the reviewed studies, underlining the increased focus on immersive methodologies over time.

Chart 1. Yearly distribution of selected studies

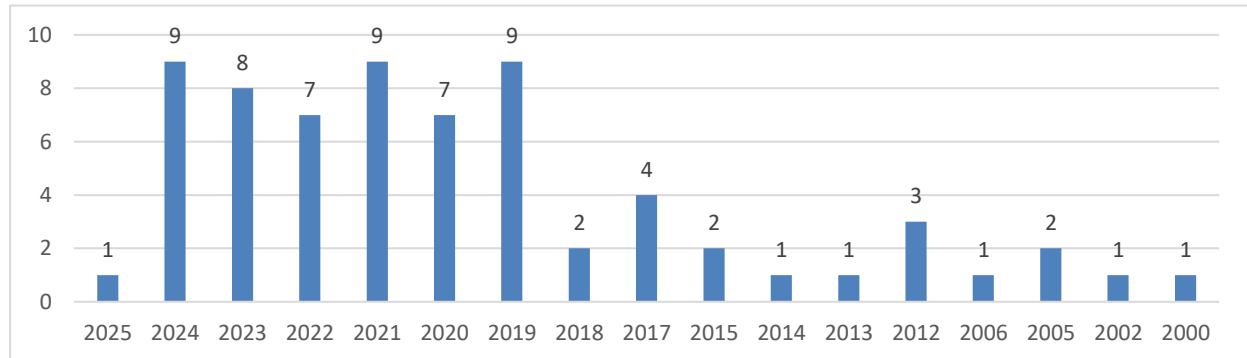


Chart 1 illustrates the distribution of publication years across 68 academic studies focused on VR applications in architectural and design education. The graph provides evidence of increased research

activity, particularly between 2019 and 2025, with publication rates peaking at nine studies per year in 2019, 2021, and 2024. Such a trend might refer to an increased interest in integrating VR technology into the field in the period in question, probably due to advances in VR technology and the quite reasonable price theretofore. Another point is that hinting at the very infant stages of application, as far as applying VR in the domain in the years like 2002 and 2005. Observing the graph, one can perceive a sharp upward trend after 2019, highlighting the growing recognition and development of VR's potential in enhancing learning within the field of architecture. The consistent flow of numbers starting from 2019 demonstrates continuous scholarly interest in and maturity through pedagogical use. This growth further underlines the relevance of VR in contemporary educational practices, and the data suggests continuing momentum that researchers may continue to draw on, availing themselves of emerging technologies and methodologies.

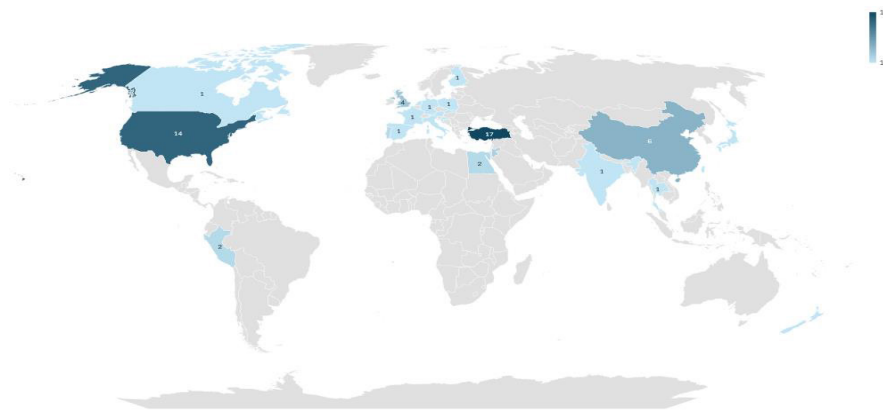


Figure 2. Country distribution of selected studies

Figure 2 illustrates the distribution of research into the use of virtual reality-based learning environments in architecture education across different nations. Of the 68 studies analyzed, the largest concentrations of research came from Turkey with 17 studies and the United States with 14 studies. Other significant contributors were China with 6 studies, while a number of countries made more minor contributions, including Egypt, Germany, and Italy. The prominence of Turkey in the current review is arguably because this review included specific Turkish research keywords that made many studies from the country more traceable. Although the prevalence of the studies in certain nations underlines unequal development and interest across areas, the representation of the nations in Asia, Europe, and North America denotes the global importance of VR-based learning in architecture education.

Chart 2. Distribution of selected studies based on publication type

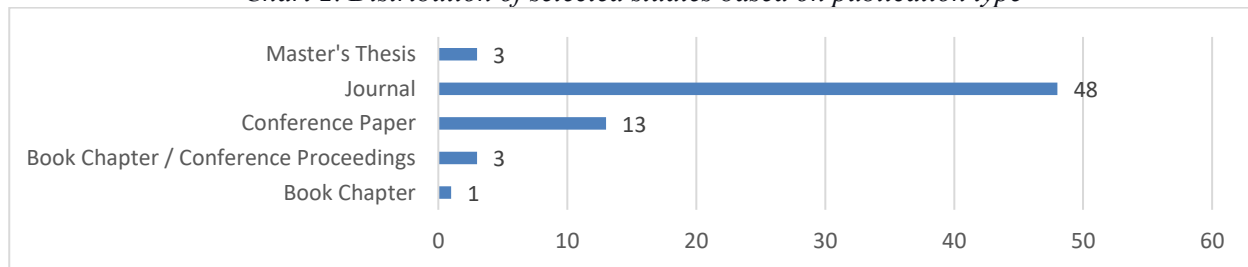


Chart 2 indicates the publication types of the 68 works under examination. Of these, the dominant group comprises 48 studies in the class of journal articles, amounting to about 71% of the total. This may mean that the most preferred channel for sharing research on VR-based learning environments in architectural

education is the peer-reviewed journals. Thirteen papers, or 19%, of the works are conference papers, showing that conferences also form an important avenue for presenting new research in this area. The representation is low for other formats, such as book chapters, at three studies, 4%, and master's theses, at one study, 1%. Three works, four percent, are also represented in the category "Book Chapter/Conference Proceedings.

Chart 3. Focus areas of selected studies

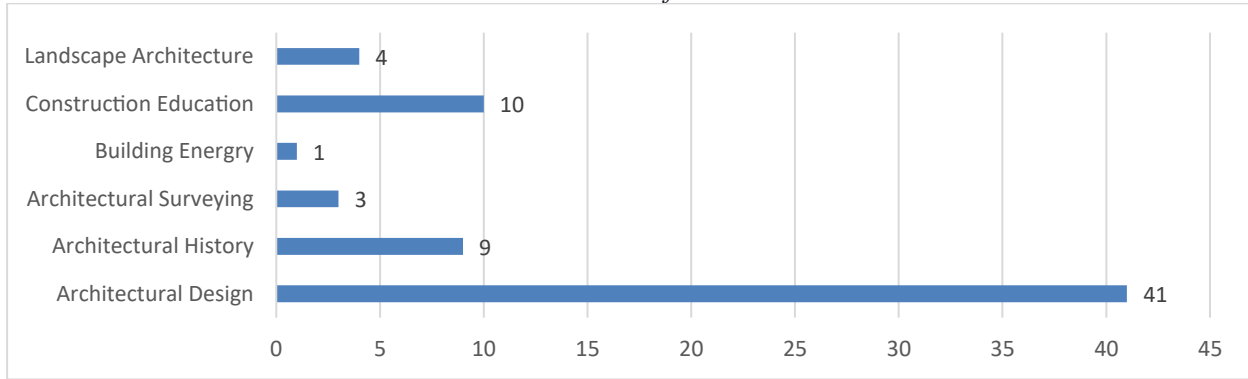


Chart 3 shows the distribution according to the subject focus of 68 studies in a greater context of architectural education using virtual reality-based learning environments. About 60%, or 41 studies, were about architectural design, which remains at the leading edge in research into VR applications in architecture. This represents great interest in learning how the use of virtual reality technology could improve visualization, creativity and other issues related to design. With 10 research (15%), construction education is the second-largest focal area, demonstrating the value of virtual reality in teaching and training students in construction-related procedures and practices. Nine works (13%) relate to architectural history and demonstrate how virtual reality serves as a tool for learning about, reconstructing, or teaching architectural history. The other fields, which account for a smaller part of the research, include Landscape Architecture with 4 studies or 6%, Architectural Surveying with 3 studies or 4%, and Building Energy 1 study or 1%. These results show that the use of virtual reality has newly found applications in subfields such as surveying or energy efficiency but have been restricted up to now.

Chart 4. Types of VR integration in selected studies

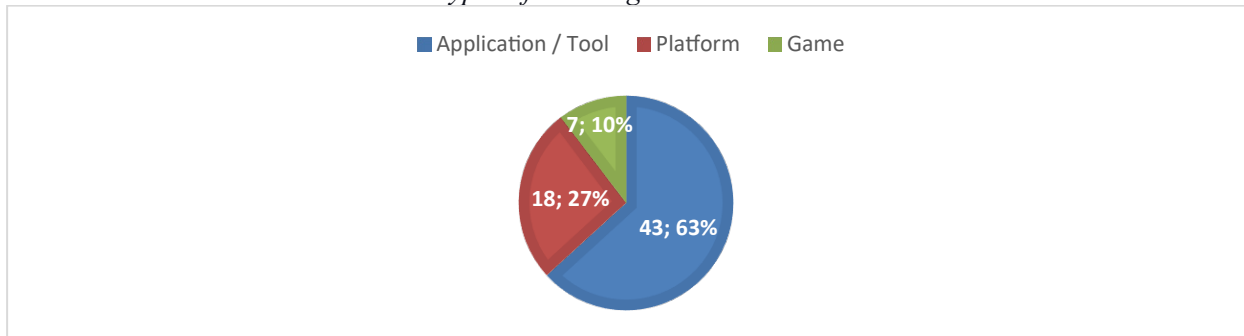


Chart 4 reflects the distribution of the studies based on their focus within VR-based learning environments in architectural education. Application/Tool, Platform, and Game are the categories under review. Application/Tool has the highest share, with 43 studies at 63%. This area indicates that most of the research involves creating customized solutions for education by either creating or making use of some sort of stand-alone program or tool designed for VR environments. The prevalence underlines the considerable relevance of exploiting virtual reality to create interactive applications for architectural education. On the other hand,

Platform 18 (27%) studies use VR as a platform or interface to investigate pre-existing models or to carry out analyses in VR. This category represents a use of VR mainly for viewing or interaction rather than creating new tools or games. The smallest portion comprises game-based learning, with seven research (10%); gamification of architectural instruction and places them into virtual reality games. Though this category is underrepresented, it can be seen that the use of gamification as a teaching method is gaining momentum in virtual environments.

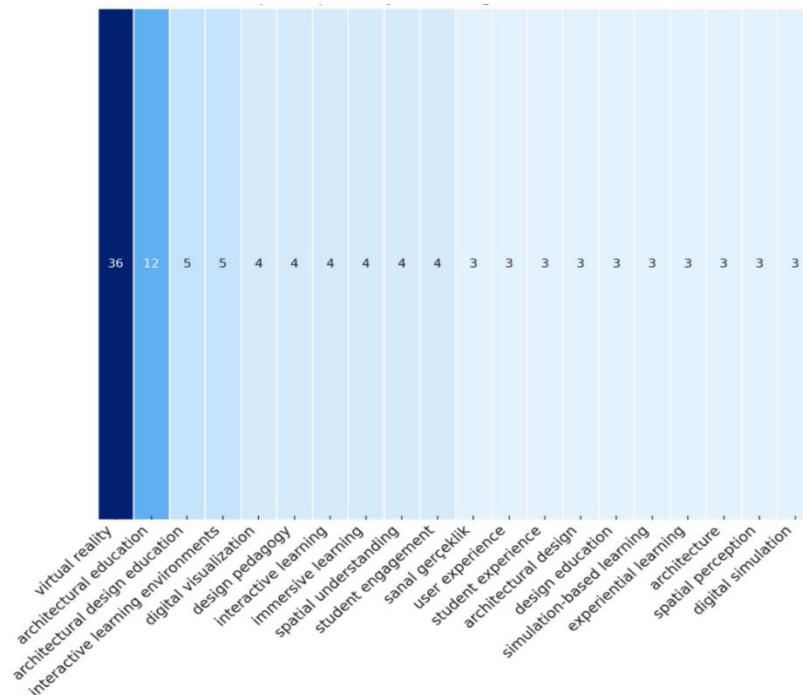


Figure 3. Keyword frequency (of the most 20) of selected studies

Figure 3. represents the frequency distribution of most used 20 keywords from 68 academic studies related to virtual reality and architectural education. In this context, the most dominant terms are virtual reality (VR), architectural education and architectural design education. The analysis focuses on keywords that appear four or more times, which can provide information on dominant research topics, educational needs, and potential gaps. The frequency of the keywords virtual reality, architectural education and architectural design education is to be expected, given the topic of the research. The studies at hand were purposefully selected as being relevant to the use of VR in architectural and design pedagogy. The frequency of the keywords is thus simply a reflection of the core thematic extent of the literature at hand rather than an indicator of an emergent or nascent trend. "Virtual reality" is the primary field of technology that is in research, and "architectural education" is the pedagogical setting wherein these technologies are implemented.

The repeated occurrence of interactive learning environments reflects the pedagogical shift towards more interactive, participatory learning experiences. VR enables interactive learning by immersing students in spatially dynamic, context-rich environments that promote active exploration and critical thinking [13]. The frequency of this keyword indicates a need to leverage VR in shifting from passive to active learning strategies. The focus on digital visualization reflects utilization of VR as a tool for supporting the re-enforcement of the visual communication of design concepts. The visualization capability of VR allows

students to grasp abstract design principles since it provides life-like, zoomable, and editable virtual environments [34]. Design Pedagogy indicates scholarly interest in the ways VR technology influences teaching methods and designs methods of instruction. The move toward tools in technology necessitates pedagogic creativity to adequately deploy VR in studio courses [27]. Frequency of this word indicates ongoing movement toward integrating good school design practice with technology-driven educational techniques. Like "interactive learning environments," interactive learning keyword maintains the teaching community's enthusiasm for creating participatory, active learning experiences. VR uses in design education often revolve around interaction as a means to enhance problem-solving and spatial reasoning skills [6]. The immersive learning theory, which closely aligns with VR's affordances, alludes to the use of VR in creating rich context-based learning. Immersion in virtual space promotes deeper thinking, as learners can experience and interact with forms of architecture within simulated worlds [26]. The usage frequency of this keyword suggests sustained interest in researching the cognitive benefits of immersion on architectural design processes. Spatial understanding is the foundation of architectural education, and the ability of VR to describe spatial relationships dynamically explains the predominance of this term [14]. Student Engagement remains a deciding factor in learning attainment, and VR's game-based, interactive nature has been shown to motivate learners [28]. The occurrence of this keyword in its accessible frequencies aligns with research demonstrating that interactive VR applications can enhance attentiveness and engagement, particularly when combined with game-based learning practices.

5. DISCUSSION

The results of this review have highlighted the huge development and diversity in the application of Virtual Reality technologies within architecture and design education. The selected studies, ranging from 2000 to 2025, indicate an accelerating interest in integrating VR tools, platforms, and games to improve learning outcomes. This might be explained by the rising interest in VR, especially after 2018, which has gone along with the enhancement of hardware and software for VR technologies and their availability within educational settings. First, improvements in VR technology at around this time probably made it more affordable and available for use in research and teaching. The advent of robust, relatively inexpensive hardware such as Meta Oculus headsets and software platforms would naturally have encouraged these researchers to investigate what virtual reality has to offer from state-of-the-art educational settings. Second, the general global trend of digital transformation, especially during and after the COVID-19 pandemic in 2020, may have accelerated the adoption of VR in education. As the pandemic created a growing demand for remote and immersive learning solutions, virtual reality emerged as a practical method to enhance engagement and participation in architectural education. Last but not least, growing awareness of the pedagogical benefits of VR-like better visualization, interactivity, and the possibility of simulating real conditions-may have contributed to the rise in study interest. The fact that researchers are increasingly becoming aware of the potential of VR to solve conventional problems in teaching and learning does indeed mark a shift in the status of this technology within architectural education. This increasing trend in VR-related research is likely to further intensify as the technology becomes increasingly integrated into teaching methodologies.

Geographical distribution of the selected studies underlines the global relevance of VR in architecture and design education, with countries such as Turkey, the United States, and China standing out. The analysis of the publication types allows seeing the dominance of journal articles, at about 71%, while the second biggest category corresponds to the conference publications. This can reflect partiality toward such publications and high importance given to peer-review research in this domain. On the other hand, conferences represent equal and important ground to present novelties or preliminary results, as shown in the case of conference papers representation. While represented to a lesser extent, master's theses and book chapters also offer insights and exploratory approaches that complement the wider literature.

The thematic distribution of the studies reveals a strong predominance of the architectural design theme, constituting the majority of the research. This dominance may suggest that VR is mainly used to support design processes, enhance spatial cognition, and develop capabilities for visualization. Other topics, such as construction education, architectural history, and landscape architecture, further reveal the flexibility of VR in responding to a wide range of educational aims. In contrast, building energy and surveying have seldom been discussed, and therefore offer some avenues for further research into new applications of VR. The very diversity of the types of VR-based approaches themselves-applications/tools, platforms, and games-emphasizes further the multifunctionality of VR in architectural education. The most prevalent category here is applications and tools, representing a focus on the creation of tailored solutions for particular educational needs. Platforms are mostly used for visualization and interaction and underline the utility of VR as a supportive interface for already existing models. Game-based learning, though underrepresented, has the potential to engage learners in interactive and gamified experiences that correspond to the current trends in serious gaming and immersive learning. The prevalence of the Application/Tool category would indicate that the researchers first focus on the development of custom VR applications, which meet certain learning objectives. The low percentage of game studies would suggest that game-based learning is still in its infancy as a discipline within architectural education and requires further research to reach its full potential. This release, focused on the development of specialized tools while considering both the use of platforms and gamification, represents the different ways in which VR can be applied to architectural education. Despite the considerable contribution of these reviewed studies, there are still important empirical gaps related to long-term influences of VR on learning outcomes and development of standardized curricula. These shortcomings should be addressed in future research: proceedings that incorporate a strong methodology, coupled with longitudinal designs, are urgently needed to determine the continued effectiveness of VR technologies. Moreover, interdisciplinary collaboration can help further increase both access and usability regarding VR equipment-a guarantee for full integration across educational settings.

6. CONCLUSION

This bibliometric review has revealed that VR technologies have been increasingly integrated into architecture and design education, demonstrating their transformative potential. It has highlighted a global interest in VR, from Europe to USA. Most of the literature has been found to be based on journal articles, reflecting the rigorous peer-review process that high-quality research typically undergoes. Thematic analysis has also highlighted architectural design as the primary focus, supported by virtual reality tools, platforms, and game-based learning environments. Additionally, it has indicated that VR can enhance spatial cognition, design understanding, and collaborative learning in studies of valuable insight into its evolving role within educational settings. Significant gaps remain in understanding the long-term impacts of VR in architectural education and the development of standardized curricula. Future research should focus on empirical studies and interdisciplinary approaches to enhance the accessibility and effectiveness of VR-based learning. This, in turn, provides a foundation for further research, guiding educators and researchers in leveraging VR technologies for innovative and immersive learning environments.

Beyond VR-based learning spaces, advancements in technologies such as Artificial Intelligence, Virtual Reality, Augmented Reality, Mixed Reality, and Extended Reality are reshaping architectural concepts, development, and execution while introducing new possibilities for creativity and efficiency. This transformation necessitates a reevaluation of pedagogy to equip future architects and designers with the necessary digital competencies while preserving spatial awareness, core design principles, creativity, and critical thinking skills. Thus, a balanced approach, supported by a restructured curriculum that integrates traditional architectural methodologies with emerging technologies, will be essential in preparing designers for an evolving professional landscape. Collaborative programs between academic institutions and

professional disciplines can play a key role in standardizing tools and methods while ensuring that educational content remains relevant to industry practices. Furthermore, longitudinal studies on the cognitive and pedagogical impact of these technologies will be crucial in refining instructional strategies and maximizing their educational value, ensuring that students are well-equipped to navigate and innovate within a technologically advanced architectural field.

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