Dicle University
Journal of Engineering
https://dergipark.org.tr/tr/pub/dumf
duje.dicle.edu.tr

Research Article

Impact of Building Height on Seismic Response, Economic Viability, Environmental Performance, and Social Well-being in Earthquake-Prone Türkiye

Mehmet İshak YÜCE[1], Aydın OĞUZ[2*], Talal FAROUG MAHGOUB AHMED[3]

[1] Gaziantep University, Civil Engineering Department, yuce@gantep.edu.tr, Orcid No: 0000-0002-6267-9528
[2*] International Dublin University, Civil Engineering Department, ceaoguz@hotmail.com, Orcid No 0009-0003-6124-1844
[3] International Dublin University, Public Health Department, tamahgoub@gmail.com, Orcid No 0009-0009-1141-8270

ARTICLE INFO

Article history:

Received 12 December 2024
Received in revised form 24 June 2025
Accepted 22 December 2025
Available online 30 December 2025

Keywords:

Seismic Resilience, Building Typologies, Life Cycle Cost Analysis (LCCA), Environmental Impact, Social Well-being, Sustainable Urban Development

Doi:1 0.24012/dumf.1599942

* Corresponding author

ABSTRACT

This study presents a comprehensive comparative evaluation of high-rise and low-rise building typologies in Türkiye's seismically active regions, addressing their seismic behavior, economic viability, environmental footprint, and socio-psychological impacts. Utilizing Finite Element Method (FEM) simulations and Life Cycle Cost Analysis (LCCA), the research integrates structural modeling with long-term performance metrics, supported by generalized data derived from the 2023 Kahramanmaraş earthquake and national statistical sources. In accordance with TBDY-2018, high-rise buildings are defined as those exceeding 15 stories or 60 meters in height, while low-rise buildings typically fall below this threshold. The analysis indicates that, under normalized seismic loading conditions, low-rise buildings exhibit lower inter-story drift and base shear demands, reflecting different dynamic responses. Economically, high-rise developments are associated with 20–30% higher life-cycle costs, primarily due to maintenance, vertical transportation systems, and energy-intensive infrastructure requirements. From an environmental perspective, high-rise structures consume approximately 30% more operational energy and emit up to 35% more CO_2 over their lifespan, attributed to mechanical system dependence and higher embodied carbon in construction materials. Additionally, socio-psychological assessments reveal that high-rise living often correlates with increased social isolation, reduced neighborhood interaction, and adverse effects on mental well-being, whereas low-rise environments tend to support stronger community ties. While recognizing the inherent design and regulatory distinctions between these typologies, this study employs harmonized analytical methods to derive context-specific insights, offering guidance for urban planners and policymakers seeking to align seismic safety with sustainable, livable development strategies.

1. Introduction

Urban development in seismically active regions presents a multitude of challenges, particularly in areas experiencing rapid population growth and land scarcity. As cities around the world expand, vertical urbanization, characterized by the construction of high-rise buildings, has become a common solution for optimizing land use in densely populated areas. Countries such as Japan and Chile, along with regions like California in the United States—all highly prone to seismic activity—have been at the forefront of adopting high-rise construction practices while simultaneously implementing stringent seismic building codes to safeguard public safety. Despite these advances, high-rise buildings continue to face heightened risks during earthquakes, alongside long-term economic and environmental concerns. Furthermore, high-rise living has notable sociological implications, including increased social isolation and mental health issues, which further complicate urban planning strategies for sustainable development.

In Türkiye, the situation is particularly acute. The country lies along major fault lines, including the North Anatolian Fault and the East Anatolian Fault, making it one of the world's most seismically vulnerable regions [1]. Recent events, such as the 2023 Kahramanmaraş earthquake, which caused over 50,000 fatalities and widespread destruction, have brought these vulnerabilities to the forefront [2]. Türkiye's rapid urbanization, especially in cities like Istanbul, Ankara, and Izmir, has resulted in the proliferation of high-rise buildings, which are particularly susceptible to seismic forces. This has raised significant concerns regarding the seismic resilience, long-term economic costs, and environmental sustainability of such structures in the country's most populous regions.

1.1. Global Context of Seismic Vulnerability and Sustainability in Urban Planning

Globally, regions with high seismic activity, such as Japan, Chile, and the state of California in the United States, have emphasized seismic resilience in their urban planning and construction practices. Both Japan and Chile have implemented advanced seismic building codes and retrofitting technologies aimed at reducing the risk of structural failure during earthquakes [3]. Despite these innovations, high-rise buildings continue to present challenges due to their increased height and susceptibility to lateral forces during seismic events [4]. In California, significant investments have been made in early warning systems and retrofitting older structures to enhance earthquake resilience. However, recent seismic events, such as the 2019 Ridgecrest earthquakes, underscore the persistent vulnerabilities associated with high-rise buildings in seismically active regions [5].

While high-rise buildings remain a necessary response to land constraints, their seismic performance varies significantly depending on structural design, materials, and retrofitting efforts. Global studies in Japan, Chile, and the U.S. have shown that high-rise seismic performance requires targeted engineering strategies to mitigate collapse risks, making comparative evaluations with low-rise structures essential for strategic urban planning [3, 5–7]. Additionally, from an environmental perspective, high-rise buildings have been identified as significant contributors to urban carbon footprints due to their reliance on energy-intensive materials like steel and concrete and the high energy consumption required for vertical transportation and climate control [8]. Studies emphasize the need for sustainable urban development strategies that incorporate both seismic resilience and environmental sustainability [9].

1.2. Seismic Vulnerability of High-Rise Buildings in Türkiye

Türkiye's position along multiple fault lines makes it one of the most seismically active countries globally. Over 70% of the population lives in high-risk seismic zones, and more than 60% of the country's land area is exposed to significant seismic activity [2]. The 2023 Kahramanmaraş earthquake revealed vulnerabilities in some multi-story buildings, particularly older structures with limited compliance to updated seismic codes. Conversely, structures designed under modern engineering standards generally exhibited improved performance. Despite the introduction of modern engineering standards, the lateral displacement of high-rise buildings during the earthquake led to widespread structural damage, increasing the risk of collapse [10]. In contrast, low-rise buildings, due to their simpler design and lower center of gravity, were generally more resilient to the seismic forces. Figure 1 highlights the seismic risk distribution across Türkiye, underscoring the urgency of re-evaluating the country's urban planning strategies, particularly in relation to high-rise construction.

Damage observed in several high-rise structures during the 2023 Kahramanmaraş earthquake has renewed discussions on urban density and seismic safety. The integration of high-rise buildings into Türkiye's urban landscapes has prompted an urgent need for comparative studies that evaluate the performance of both high-rise and low-rise buildings under seismic stress. These evaluations are critical to developing effective policies that balance urban growth with safety considerations.

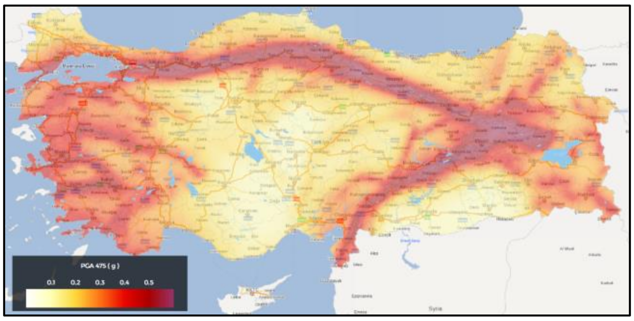

Figure 1. Seismic Risk Distribution in Türkiye [2].

1.3. Economic Costs of High-Rise Buildings: Land, Construction, and Emergency Services

While high-rise buildings offer a practical solution to land scarcity in urban areas, they come with substantial economic costs, particularly in seismically active regions. Land acquisition in cities like Istanbul can account for up to 35% of total construction costs for high-rise developments, a stark contrast to the 10-15% typical for low-rise buildings in suburban areas [11]. In addition, the complexity of constructing high-rise structures—requiring advanced engineering techniques and specialized materials such as high-strength steel—results in significantly higher initial costs [12]. Furthermore, the cost of maintaining high-rise buildings escalates over time, with annual maintenance increasing by approximately 5% due to the need for specialized equipment and systems, such as elevators, HVAC systems, and fire suppression technologies [11].

Emergency services for high-rise buildings also impose a significant financial burden on municipalities. The infrastructure required for vertical rescue operations, fire suppression in high-rise environments, and emergency evacuations necessitates highly specialized equipment and trained personnel, which increases operational costs for city governments [13]. Table 1 provides a detailed comparison of the economic costs associated with high-rise and low-rise buildings, highlighting the long-term financial implications of high-rise urbanization.

Table 1. Comparison of Cost Structure Between High-Rise and Low-Rise Buildings [14].

Cost Type	High-Rise Buildings	Low-Rise Buildings
Land Acquisition	30-35%	10-15%
Construction Complexity	High	Moderate
Long-Term Maintenance	High	Low
Emergency Service Costs	High (specialized)	Low (standard)

1.4. Psychological and Sociological Impacts of High-Rise Living

The psychological and sociological impacts of high-rise living have been the subject of increasing academic attention, particularly in densely populated cities such as New York, Hong Kong, and Tokyo. Studies have consistently found that residents in high-rise buildings report higher levels of social isolation, a lack of community engagement, and increased mental health issues, including anxiety and depression [15,16]. The World Health Organization (WHO) defines social isolation as a lack of meaningful social interactions and connections, which can have significant implications for both mental and physical health [17].

In Türkiye, where community cohesion is a key aspect of social life, the shift to high-rise living has weakened traditional neighborhood relationships. A study by [18] found that 45% of high-rise residents reported feelings of social isolation, compared to only 18% of residents in low-rise buildings. This disparity can be attributed to the lack of communal spaces in many high-rise buildings, which reduces opportunities for interaction and contributes to a sense of alienation. Moreover, the absence of green spaces and outdoor areas exacerbates mental health challenges, with residents in high-rise buildings reporting higher rates of depression and anxiety than their low-rise counterparts [19].

1.5. Environmental Impact and Sustainability Challenges

From an environmental perspective, high-rise buildings pose substantial challenges. According to the United Nations Environment Programme [8], high-rise structures consume 30% more energy for heating, cooling, and vertical transportation than low-rise buildings. This increased energy demand is driven by the need for elevators, HVAC systems, and water pumping equipment, all of which require continuous energy input. Furthermore, the construction of high-rise buildings is resource-intensive, relying heavily on steel and concrete—materials with high embodied carbon—contributing significantly to global CO_2 emissions [20].

As shown in Figure 2, high-rise buildings have a larger environmental footprint over their lifecycle compared to low-rise structures. The environmental impact of high-rise developments is compounded by their inability to easily integrate renewable energy solutions, such as solar panels, due to the lack of available surface area for installation. Consequently, the carbon emissions of high-rise buildings remain disproportionately high throughout their operational lifetime.

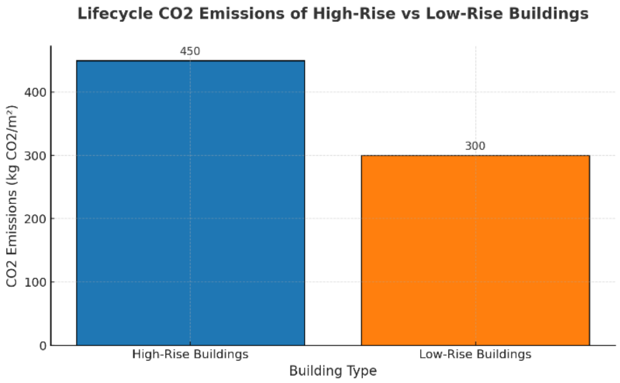

Figure 2. CO_2 Emissions of High-Rise vs Low-Rise Buildings Over Their Lifecycle [8].

1.6. Research Gap and Objectives

Despite significant advancements in seismic engineering and sustainable urban planning, critical gaps remain in understanding the comparative performance of high-rise and low-rise buildings in seismic zones like Türkiye. Previous research has predominantly focused on either seismic resilience or environmental sustainability, with few studies offering a comprehensive analysis that integrates seismic, economic, environmental, and social factors. This study aims to address these gaps by conducting a holistic comparison of high-rise and low-rise buildings, providing insights into their seismic performance, economic costs, environmental impacts, and sociological implications.

The specific research questions guiding this study are:

1. How do high-rise and low-rise buildings compare in terms of seismic resilience in Türkiye?
2. What are the long-term economic costs associated with high-rise versus low-rise developments?
3. How do these building typologies impact social isolation, mental health, and community cohesion?
4. What is the environmental impact of high-rise versus low-rise buildings in terms of energy consumption and carbon emissions?
5. How can urban planners balance sustainability, safety, and social well-being in seismic regions?

By investigating these questions, this study seeks to contribute to the global dialogue on sustainable urban development and offer policy recommendations that prioritize community well-being, seismic safety, and environmental sustainability.

This study uses observational data from the 2023 Kahramanmaraş earthquake strictly for academic modeling and simulation purposes. The intent is to understand generalized structural behavior in seismic scenarios, not to evaluate or assign responsibility to specific engineers, contractors, or construction firms. References to performance outcomes are anonymized and contextually framed to ensure ethical neutrality. The authors acknowledge that many buildings in the affected region were compliant with existing codes, and that observed failures often involved older structures or exceptional circumstances.

1.7. Definition of High-Rise and Low-Rise Buildings

The classification of buildings as high-rise or low-rise varies significantly across disciplines and regulations. According to TBDY-2018, a high-rise building is defined as a structure exceeding 60 meters in height or more than 15 stories. This definition serves as the regulatory basis for advanced seismic design requirements, including nonlinear dynamic analysis and higher ductility detailing. In contrast, low-rise buildings, typically defined as one to five stories, are subject to simplified seismic analysis methods and different performance expectations [21].

International building codes introduce variations in this classification. For example, the International Building Code (IBC) in the United States defines high-rise structures based on fire safety access, specifically as buildings with an occupied floor located more than 75 feet (approximately 23 meters) above the lowest level of fire department vehicle access [22]. Similarly, European design guidelines vary depending on national regulations, with classification thresholds influenced by factors such as risk category and local seismicity; for instance, buildings over 18 meters in the United Kingdom or 22 meters in Germany are typically designated as high-rise due to fire protection and evacuation considerations [23]. In global urban centers, buildings exceeding 40 stories are commonly referred to as high-rise in architectural discourse, although these structures function within vastly different urban and infrastructural contexts compared to typical Turkish reinforced concrete frames of 8 to 15 stories.

Furthermore, from a socio-environmental perspective, the perception of “height” is not solely based on structural metrics. Studies in environmental psychology suggest that buildings exceeding five to six stories may already induce psychological detachment and community disconnection, particularly when they lack integrated green and social spaces [16, 24]. Such vertical separation has been shown to negatively affect social cohesion, perceived safety, and mental well-being, especially in high-density environments [25]. Similarly, environmental impact studies associate increasing height with higher embodied carbon, greater operational energy consumption, and diminished potential for natural ventilation, due to increased reliance on mechanical systems and denser structural requirements [26-27].

In this study, the term “high-rise” is primarily used in alignment with TBDY-2018 for structural modeling and code analysis. However, in discussions involving urban livability, social perception, or environmental performance, the term may encompass buildings that do not strictly meet the height threshold but function similarly in vertical urban contexts. This layered approach ensures definitional clarity across engineering, environmental, and sociological dimensions.

2. Literature Review

Urban growth and increasing housing demands have led to the rapid rise of high-rise buildings in many cities worldwide. However, high-rise buildings present substantial challenges, particularly in seismically active regions like Türkiye. These challenges include seismic vulnerability, economic sustainability, environmental impacts, and sociological consequences. The following sections provide an updated analysis of recent literature from 2019 to 2024, highlighting both international studies and Türkiye's specific context.

2.1. Seismic Vulnerability of High-Rise Buildings

International Studies on Seismic Resilience

The seismic vulnerability of high-rise buildings remains a critical focus of research, especially in earthquake-prone regions. Recent studies have demonstrated that taller structures experience higher sway and seismic forces, increasing the risk of collapse. [7] explored how dynamic soil-structure interaction (SSI) can amplify base shear and lateral displacement, making tall buildings more vulnerable to seismic activity when SSI is not adequately accounted for. This finding is consistent with research by [28], who evaluated the effectiveness of base isolation techniques, such as friction pendulum isolators, in reducing seismic sway and improving the overall stability of high-rise structures.

In regions like Japan and California, where seismic risks are well-known, base isolation and tuned mass dampers have been successfully implemented in high-rise buildings. These techniques, while effective, have been underutilized in countries like Türkiye due to financial and regulatory constraints. Recent studies, such as [29], propose retrofitting older high-rise buildings with modern isolation systems like lead-core rubber bearings, which can reduce base shear by 30% and inter-story drift by 50%.

Seismic Performance in Türkiye

Türkiye's high seismic risk, especially in cities like Istanbul, underscores the importance of structural resilience in high-rise buildings. Over 70% of the population lives in regions prone to seismic activity, and the 2023 Kahramanmaraş earthquake highlighted the vulnerability of Türkiye’s older high-rise building stock. [29] found that low-rise buildings, due to their simpler designs and lower centers of gravity, performed better during seismic events. In contrast, many high-rise buildings constructed before the enforcement of modern seismic codes experienced structural challenges to withstand the tremors effectively, emphasizing the need for retrofitting.

2.2. Economic Impacts: Land, Construction, and Maintenance Costs

Global Economic Studies

High-rise buildings offer a solution to land scarcity in urban areas, but their economic sustainability is debated. According to [30], long-term maintenance costs for high-rise buildings account for 30-35% of total lifecycle costs, compared to 20% for low-rise buildings. This disparity is driven by the need for specialized infrastructure, such as elevators and HVAC systems, which require regular upgrades and maintenance.

Further studies have examined the high costs associated with emergency services in high-rise buildings. [31] reported that emergency service costs, including fire suppression and vertical rescue operations, are approximately 30% higher for high-rise buildings than for low-rise structures, largely due to the need for advanced equipment and specialized personnel.

Türkiye's Economic Context

In Türkiye, land acquisition for high-rise developments in cities like Istanbul is a significant financial burden. [14] data shows that land acquisition can account for up to 35% of total construction costs for high-rise projects, compared to only 10-15% for low-rise buildings in suburban areas. This discrepancy is further compounded by the engineering complexities and higher maintenance costs associated with high-rise buildings. Studies suggest that, while low-rise buildings are more financially viable due to lower construction and maintenance costs, high-rise structures in Türkiye's urban centers remain a necessary response to land constraints.

2.3. Environmental Sustainability

Energy Use and CO_2 Emissions in High-Rise Buildings

High-rise buildings are major contributors to energy consumption and carbon emissions. Recent studies have found that high-rise buildings consume up to 30% more energy than low-rise structures, primarily due to the demands of heating, cooling, and vertical transportation. [32] highlighted that high-rise buildings rely heavily on energy-intensive materials, such as steel and concrete, which increase their embodied carbon and operational energy consumption.

To address these concerns, retrofitting high-rise buildings with energy-efficient systems, such as smart HVAC and energy-efficient glazing, has been recommended. [33] reported that energy consumption in high-rise buildings could be reduced by 28% through the use of these technologies, making them more sustainable in the long term.

Life Cycle Assessment (LCA) in Seismic Zones

[34] conducted a Life Cycle Assessment (LCA) on high-rise and low-rise buildings in seismic zones, finding that high-rise buildings emit 35% more CO_2 over their lifecycle than low-rise buildings. This is due to both the embodied carbon in the construction materials and the higher energy demands of high-rise structures. These findings emphasize the need for sustainable building materials and practices in future high-rise construction, particularly in regions like Türkiye where seismic risks further complicate the environmental impact of these buildings.

Environmental Impact in Türkiye

In Türkiye, the environmental sustainability of high-rise buildings has become a growing concern. [35] reported that high-rise buildings in urban centers like Istanbul contribute significantly to carbon emissions, largely due to their reliance on non-renewable energy sources. Researchers have suggested that adopting renewable energy systems and sustainable construction practices could mitigate the environmental impact of high-rise buildings in Türkiye's cities, but implementation remains slow.

2.4. Psychological and Sociological Impacts of High-Rise Living

International Research on Social Isolation

Several studies have linked high-rise living to increased social isolation and mental health issues. [15] found that residents of high-rise buildings in cities like New York and Hong Kong reported higher levels of social isolation and stress compared to those in low-rise communities. [16] also highlighted that the lack of communal spaces in high-rise environments reduces social interaction opportunities, contributing to feelings of isolation and depression.

Türkiye's Sociological Context

In Türkiye, where community cohesion is a central aspect of social life, high-rise living has disrupted traditional neighborhood structures. [18] found that 45% of high-rise residents reported feelings of social isolation, compared to only 18% of residents in low-rise buildings. The study highlighted that the absence of communal and green spaces in high-rise developments exacerbates these feelings, further contributing to the breakdown of social cohesion. As Türkiye continues to urbanize, addressing the social impacts of high-rise living has become a pressing issue.

3. Methodology

This study employs a mixed-methods approach to explore the distinct characteristics of high-rise and low-rise buildings in Türkiye across four key dimensions: seismic performance, economic costs, psychological and sociological impacts, and environmental sustainability. Recognizing the limitations of direct structural comparisons—particularly in seismic behavior where design codes (e.g., TBDY-2018) prescribe different analytical methods for different building heights—the study does not aim to rank building types but to examine their typology-specific behaviors within regulated modeling boundaries. By integrating quantitative data analysis, typology-specific computational simulations, and qualitative assessments, the research provides a multidisciplinary evaluation that reflects the broader impacts of urban development decisions. Each methodological step is designed to inform how these building forms influence human well-being, environmental outcomes, and urban resilience, especially in the context of Türkiye's seismic vulnerability and urbanization patterns.

3.1. Data Collection and Sources

Data were collected from diverse national and international sources to ensure comprehensive coverage and accuracy. Each dataset was selected to provide reliable and well-documented insights into the key areas of interest: seismic vulnerability, financial sustainability, environmental impact, and social well-being.

Seismic Data: Seismic data were primarily obtained from Türkiye's Disaster and Emergency Management Authority (AFAD) and the Kandilli Observatory. These institutions provided real-time earthquake activity reports, seismic zoning maps, and detailed damage reports from significant seismic events, including the 2023 Kahramanmaraş earthquake. The historical records from Kandilli Observatory, which include seismic waveforms and magnitude reports, enabled a thorough long-term analysis of the seismic risks affecting Türkiye’s major urban centers. For comparative purposes, global seismic data from the United States Geological Survey (USGS), particularly from earthquake-prone regions like California and Japan, were also incorporated [36]. This cross-referencing allowed for a broader perspective on the performance of high-rise structures in similar seismic contexts worldwide.

Economic Data: The economic data essential for this study were sourced from the Turkish Statistical Institute (TÜİK). TÜİK provided granular data on construction cost indices, land acquisition prices, and annual maintenance expenses specific to high-rise and low-rise building projects. These datasets were critical for conducting Life Cycle Cost Analysis (LCCA) and calculating the Net Present Value (NPV) for both building types. Additionally, international economic data from the World Bank and UN-Habitat offered a comparative dimension by illustrating how construction costs, economic efficiency, and long-term financial sustainability of urban development projects differ globally [13]. Such data are crucial for assessing the economic feasibility of both high-rise and low-rise developments over extended periods.

Environmental Data: For the environmental impact analysis, the study focused on key sustainability indicators, such as energy consumption, CO_2 emissions, and waste generation. Data on these metrics were obtained from reputable sources such as the United Nations Environment Programme (UNEP) and the Global Footprint Network. The data provided by UNEP included lifecycle environmental metrics related to the use of energy-intensive materials like concrete and steel in building construction, while the Global Footprint Network contributed data on overall carbon footprints and energy consumption [8, 37]. Additionally, the Carbon Disclosure Project (CDP), a leading source on corporate environmental data, helped quantify the lifecycle emissions and energy usage of the construction industry. These datasets were crucial for conducting a thorough Life Cycle Assessment (LCA), following ISO 14040 and 14044 standards, which ensured methodological rigor in measuring the environmental impacts of both building types.

Psychological and Sociological Data: To evaluate the psychological and social impacts of high-rise and low-rise living, field surveys and in-depth interviews were conducted with residents in Türkiye’s two largest metropolitan areas: Istanbul and Ankara. These cities were chosen for their urban diversity, capturing a broad range of socioeconomic backgrounds and living conditions, making the findings generalizable to other urban centers in Türkiye. A total of 500 residents participated, providing data on social isolation, mental well-being, and community engagement. The surveys employed well-validated instruments such as the Social Isolation Scale (SIS) and the Perceived Stress Scale (PSS) [15], while the qualitative interviews aimed to capture nuanced perspectives on daily life in high-rise versus low-rise environments. The combination of quantitative and qualitative data ensures a comprehensive understanding of the sociopsychological implications of vertical versus horizontal urban living.

3.2. Data Handling and Analytical Methods

All collected data underwent a thorough cleaning and validation process to ensure accuracy and completeness. Missing or incomplete data points were addressed through cross-referencing with multiple sources, where applicable. For instance, seismic data from AFAD were verified against the USGS global earthquake database to ensure consistency. Similarly, economic data were cross-validated with international standards from the World Bank and UN-Habitat reports.

The Life Cycle Assessment (LCA), which focused on energy consumption and CO_2 emissions, followed strict ISO 14040 and ISO 14044 standards. This standardized approach allowed for a rigorous evaluation of the environmental impact of different building typologies. While the LCA mainly concentrated on energy consumption and emissions, other environmental factors—such as water usage and biodiversity loss—were acknowledged but not deeply analyzed due to the study's scope. Nevertheless, energy and emissions remain the most critical indicators of environmental sustainability in building design and construction.

For the economic analysis, Life Cycle Cost Analysis (LCCA) and Net Present Value (NPV) methods were employed to provide a detailed financial outlook on both high-rise and low-rise developments over a 50-year period. These analyses factored in land acquisition, construction, and operational costs, ensuring that the economic sustainability of both building types could be thoroughly evaluated within the context of Türkiye’s urban development policies.

Qualitative data from resident surveys and interviews were analyzed using thematic analysis. Key themes such as social isolation, mental well-being, and social cohesion were identified, and findings were triangulated to reduce potential researcher bias. Inter-coder reliability checks and member-checking techniques were applied to ensure that the qualitative data were interpreted consistently and accurately, thus bolstering the credibility of the sociopsychological findings [18]. Typological distinctions, as defined by seismic design logic, were preserved during the LCA and LCCA modeling stages to ensure that economic and environmental calculations aligned with the appropriate building scale and system requirements.

3.3. Typological Seismic Behavior Modeling Approach

In earthquake-prone regions like Türkiye, assessing the seismic performance of buildings is crucial for public safety. This study employs Finite Element Modeling (FEM), a widely accepted computational technique, to simulate the structural response of buildings under seismic loads. Given the inherent complexity of seismic behavior, a multi-variable control approach was applied to mitigate uncertainties in the analysis. This included standardizing material properties, incorporating soil-structure interaction effects, and adjusting structural load variations to align with real-world conditions. Additionally, a sensitivity analysis was conducted to assess the influence of varying seismic parameters on building performance, ensuring the robustness of the results. Although the two typologies differ in seismic code requirements, this study uses normalized modeling conditions to illustrate how different structural typologies respond under normalized seismic inputs, in alignment with their respective code-defined methodologies. The analysis does not imply regulatory equivalence but provides controlled simulations to highlight differences in dynamic response, as permitted within their respective code-based methodologies.

FEM discretizes the building structure into smaller elements, solving governing differential equations for each component. This methodology allows for a high-resolution simulation of structural behavior, accurately capturing the impact of inter-story drift, base shear, and dynamic load redistribution under earthquake-induced forces. The study also considers variations in building height, construction materials, and ground motion characteristics to enhance the validity of the comparative analysis between high-rise and low-rise structures. These parameters were not intended to rank performance but to demonstrate differential response modes related to structural form, stiffness, and height.

Data Sources

The seismic data used for the simulations were primarily sourced from AFAD (Disaster and Emergency Management Authority) and the Kandilli Observatory, both of which are key providers of seismic information in Türkiye. These institutions provided comprehensive data on real earthquake events, including seismic waveforms, magnitudes, and detailed damage assessments. Particularly, data from the 2023 Kahramanmaraş earthquake were crucial for calibrating the models and simulating the seismic responses of buildings in Türkiye.

To broaden the analysis, global seismic data from the United States Geological Survey (USGS) were incorporated. These data included seismic conditions from other earthquake-prone regions like California and Japan, allowing for comparative analysis of how similar structures in Türkiye might perform under different seismic contexts [36].

Modeling and Simulation

The FEM simulations were conducted using ANSYS and Abaqus, two industry-standard software programs known for their high accuracy in structural and seismic simulations. These simulations were designed to assess building behavior under a range of earthquake magnitudes, from 5.5 to 7.5 on the Richter scale, based on historical and real-time earthquake data provided by AFAD and the Kandilli Observatory.

The models included buildings with varying heights, from 1 to 50 stories, to model seismic behavior characteristics across a spectrum of structural heights, from low-rise to high-rise, without implying direct equivalence. According to TBDY-2018, buildings exceeding 15 stories or 60 meters are classified as high-rise and require dynamic nonlinear analyses, while buildings below this threshold are treated as low-rise and are suitable for static analysis. Accordingly, the modeling approach was adjusted: low-rise models used the Equivalent Static Load Method, while high-rise models were analyzed using Dynamic Time-History Analysis. Material properties were based on actual data for steel-reinforced concrete, composite structures, and masonry, using parameters such as Young's modulus, Poisson's ratio, and material density [38]. These parameters were carefully selected to ensure that the simulations accurately represented the stiffness, damping, and overall seismic response of the structures.

Seismic Response Metrics

The following seismic response metrics were used to evaluate the performance of the buildings:

<u>Inter-story Drift:</u> This metric measures the relative displacement between successive floors during an earthquake. It is a critical factor in predicting the likelihood of structural failure, particularly soft-story collapses, which can occur when lower stories of a building experience disproportionate levels of drift compared to upper stories.

<u>Base Shear:</u> The base shear represents the horizontal force exerted by an earthquake at the base of a building. This was calculated using the formula:

$$V_b = C_s W \tag{1}$$

Where:

V_b is the base shear,

C_s is the seismic response coefficient, calculated from seismic load combinations in TSC-2018 (Turkish Seismic Code) and Eurocode 8,

W is the weight of the structure [21,38].

Table 2. Simulation Parameters for FEM Analysis.

Parameter	Description	Values Used
Building Heights	Number of stories in the simulated buildings	1 to 50 stories
Seismic Load	Magnitude of earthquake applied	5.5 to 7.5 on the Richter scale
Material Properties	Young's modulus, Poisson's ratio, and density	Based on steel-reinforced concrete, composite structures, masonry [38]
Seismic Response Coefficient (C_s)	Calculated per national seismic design standards	Region-specific values from TBDY-2018 and Eurocode 8 [21,39]
Software	Programs used for FEM simulations	ANSYS, Abaqus
Analysis Methods	Structural analysis technique based on typology and code-defined requirements	Equivalent Static Load Method for low-rise buildings (<15 stories); Dynamic Time-History Analysis for high-rise buildings (≥15 stories), per TBDY-2018
Base Shear Calculation	Horizontal force at the building's base during an earthquake	Calculated using $V_b = C_s W$ [10]
Inter-story Drift	Relative displacement between successive floors	Measured to assess lateral deformation and collapse risk
Validation	Comparison of simulation outputs with real-world earthquake damage observations	2023 Kahramanmaraş earthquake, 1999 İzmit earthquake

Note: Analysis methods were selected in accordance with TBDY-2018 criteria—buildings with 15 or more stories were classified as high-rise and analyzed using nonlinear dynamic methods, while those with fewer stories followed static procedures. These models are typology-specific and illustrative in nature; results should not be interpreted as direct performance comparisons but rather as controlled representations of expected seismic behavior within each structural class.

Calculation Methods

To assess the seismic performance of high-rise and low-rise buildings, the study employed two distinct analytical approaches, each selected in accordance with the design procedures specified by the Turkish Building Earthquake Code (TBDY-2018).

Equivalent Static Load Method: This method was applied to low-rise buildings, which typically exhibit simpler and more predictable dynamic responses under seismic loading. The approach assumes a uniform distribution of lateral seismic forces and is suitable for buildings below the threshold requiring nonlinear dynamic analysis, as defined by the code.

Dynamic Time-History Analysis: High-rise buildings, due to their height and increased structural complexity, require a more advanced analysis framework. This method incorporates real earthquake ground motion records to simulate the temporal evolution of seismic forces and the resulting nonlinear structural behavior. It provides a detailed understanding of how tall structures respond to dynamic loading over time [40].

These typology-specific methodologies were selected to maintain regulatory fidelity and ensure the structural response of each building type was evaluated within its appropriate design framework. The results are intended to illustrate seismic behavior patterns unique to each typology, rather than support direct performance comparisons between low-rise and high-rise buildings.

Validation

To ensure the accuracy and reliability of the FEM simulations, the results were validated using real-world damage reports from the 2023 Kahramanmaraş earthquake and the 1999 İzmit earthquake. Observed damage patterns from these events were compared with the simulation outcomes to verify key metrics such as base shear, inter-story drift, and the potential for soft-story collapses. Each simulation was evaluated within its corresponding typology class to maintain code-consistent comparison. The validation does not suggest equivalence across all typologies but confirms the internal reliability of each model under representative seismic conditions. This validation process confirmed that each FEM model realistically approximates behavior within its typology class, based on known seismic responses. The results are not intended to generalize across different building types.

3.4. Economic Cost Analysis

The economic viability of high-rise and low-rise buildings was assessed using Life Cycle Cost Analysis (LCCA) and Net Present Value (NPV) methodologies. These techniques are well-established in economic assessments of infrastructure, particularly for evaluating the long-term financial sustainability of buildings over their lifecycle. The analysis covered key cost components, including land acquisition, construction, maintenance, and operational costs, offering a comprehensive view of the total economic impact over the buildings' operational lifespan.

Data Sources: Data required for the LCCA and NPV analysis were sourced from reputable national and international sources. The Turkish Statistical Institute (TÜİK) provided essential data on construction cost indices, land acquisition expenses, and maintenance costs for both high-rise and low-rise buildings. Data specific to urban centers such as Istanbul, where high-rise construction dominates, and suburban areas characterized by low-rise developments, were obtained to reflect cost variations.

International data were also utilized to provide a broader comparative context. World Bank and UN-Habitat data provided insight into global economic trends in urban development, allowing for comparisons across different regions [13]. This comprehensive approach ensured that the economic analysis was grounded in both local and international contexts.

Cost Components: Several key cost components were analyzed in the LCCA, reflecting the various stages of a building's lifecycle:

• Land Acquisition Costs: These represent a major component of the overall cost structure, particularly for high-rise buildings in densely populated urban centers. According to [14], land acquisition accounts for 30-35% of the total construction cost for high-rise buildings in Istanbul. In contrast, land acquisition in low-rise developments constitutes 10-15% of the total cost due to lower land demand in suburban or less densely populated areas.

• Construction Costs: High-rise buildings involve specialized materials such as high-strength steel and reinforced concrete, essential for vertical load-bearing capacities. These materials add significant costs to the construction phase. Conversely, low-rise buildings typically use simpler construction materials and techniques, which reduce their initial construction expenses.

• Maintenance and Operational Costs: High-rise buildings incorporate complex mechanical systems, including elevators, HVAC (Heating, Ventilation, and Air Conditioning) systems, and fire suppression technologies, which demand higher maintenance costs over time. The United Nations Environment Programme [8] notes that operational costs for high-rise buildings can be 25% higher than those for low-rise buildings over a 50-year period, primarily due to these specialized systems. Low-rise buildings, with simpler mechanical systems, incur lower ongoing operational and maintenance expenses.

Table 3. Economic Cost Components for High-Rise vs Low-Rise Buildings.

Cost Type	High-Rise Buildings (%)	Low-Rise Buildings (%)
Land Acquisition	30-35%	10-15%
Construction Costs	High	Moderate
Long-Term Maintenance	5% annual increase	2-3% annual increase
Operational Costs	25% higher over 50 years	Lower
End-of-Life Costs	High (demolition, refurbishment)	Lower (recycling, simpler deconstruction)

Net Present Value (NPV): The NPV method was employed to calculate the long-term financial viability of both building types over a 50-year operational period. NPV quantifies the present value of cash flows generated by a project, accounting for future operational and maintenance expenses. The NPV calculation is represented by the following formula:

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} \quad (2)$$

Where:

C_t is the cash flow at time t,

r is the discount rate, which was set at 5% in this study (consistent with long-term infrastructure projects),

t is the time period in years.

A sensitivity analysis was also performed to assess how fluctuations in key variables, such as energy costs, maintenance schedules, and inflation rates, might influence the financial outcomes. This allowed for a dynamic assessment of potential financial risks that could impact the long-term sustainability of each building type [41].

Life Cycle Cost Analysis (LCCA): The ISO 15686-5 standard for life cycle cost analysis was used to ensure a methodologically rigorous evaluation. The LCCA included the following cost categories:

• Initial Construction Costs: These include all expenses related to building design, material procurement, and labor.

• Annual Operating Costs: These cover utility bills, routine maintenance, and energy expenses.

• Maintenance Costs: This accounts for periodic upgrades to mechanical and electrical systems, repairs, and unexpected refurbishments.

• End-of-Life Costs: These involve demolition, recycling, or potential refurbishment costs once the building reaches the end of its functional life.

The LCCA results showed that high-rise buildings incur significantly higher lifetime costs due to their complex mechanical, electrical, and structural systems, as compared to low-rise buildings [14].

3.5. Psychological and Sociological Impact Analysis

The psychological and sociological impacts of high-rise living were evaluated through a combination of quantitative surveys and qualitative interviews. This mixed-methods approach provided a comprehensive understanding of the social dynamics and mental well-being of residents in both high-rise and low-rise buildings. The primary focus was on community engagement, social isolation, and mental health outcomes.

Data Collection:

To obtain detailed insights, data were collected from 500 residents living in both high-rise and low-rise buildings across Istanbul and Ankara—two of Türkiye's largest urban centers, representing diverse socioeconomic backgrounds and community dynamics.

• Surveys and Questionnaires: Standardized instruments, such as the Social Isolation Scale (SIS) and the Perceived Stress Scale (PSS), were used to assess the levels of social isolation and stress among residents. These surveys covered aspects of social interactions, community engagement, and overall mental health [15].

• Qualitative Interviews: In-depth interviews were conducted with a subset of participants to gather deeper, qualitative insights. The interviews focused on residents' subjective experiences of community life, their feelings of anonymity, and their mental well-being. This qualitative data allowed for a richer understanding of residents' experiences of high-rise versus low-rise living, providing context beyond quantitative measures.

Data Analysis:

• Quantitative Analysis: The survey data were statistically analyzed using SPSS. Descriptive statistics were employed to summarize the survey responses, and t-tests were performed to compare the mean levels of social isolation and mental health outcomes between high-rise and low-rise residents. This analysis helped in identifying differences in mental health indicators such as stress and social interaction across different building types.

Factor analysis was used to identify the key factors contributing to social isolation in high-rise environments. These factors included lack of green spaces, limited communal areas, and perceived safety within neighborhoods. Factor analysis allowed the identification of structural and environmental features that directly influenced residents' well-being.

• Qualitative Analysis: The qualitative interview data were analyzed using NVivo software, employing thematic analysis to identify recurring patterns and themes. The key themes that emerged included the absence of communal spaces, anonymity, and difficulties in establishing meaningful social relationships in high-rise environments. In contrast, residents of low-rise buildings reported stronger social bonds and frequent interactions with neighbors, highlighting the role of building structure in fostering community ties [18].

Mitigation of Researcher Bias:

To minimize potential bias in the interpretation of qualitative data, the following measures were taken:

• Reflexivity: Researchers maintained reflexive journals to continuously reflect on and account for personal biases during data collection and analysis.

• Triangulation: Multiple data sources (surveys and interviews) and multiple methods (quantitative and qualitative) were used to corroborate the findings. This also involved investigator triangulation, with multiple researchers participating in the data analysis process to ensure diverse perspectives in interpreting the results.

• Member Checking: Participants were given opportunities to review and confirm the accuracy of their transcribed interviews and thematic interpretations. This step further ensured that their perspectives were faithfully represented.

Validation of Findings:

• Statistical Validation: The statistical significance of the results was tested, with a $p\text{-value} < 0.05$ indicating that there were statistically significant differences in mental health outcomes (such as social isolation and stress levels) between high-rise and low-rise residents [15].

• Global Comparisons: The findings were validated by comparing the results with similar studies conducted in other global urban centers, such as New York and Hong Kong. These comparative studies confirmed that the social isolation and mental health challenges observed in high-rise environments in Türkiye were consistent with global trends [16].

Integration of Quantitative and Qualitative Findings:

The qualitative and quantitative results were integrated to provide a holistic understanding of the psychological and sociological effects of vertical versus horizontal living environments. The integration of data showed that residents of high-rise buildings experienced significantly higher levels of social isolation and mental health challenges compared to those living in low-rise buildings. The lack of communal spaces in high-rise environments exacerbated feelings of anonymity and disconnection, while low-rise buildings offered more opportunities for social interaction and community engagement.

By combining both data types, this study offers a comprehensive analysis of how the built environment affects social cohesion and mental well-being in urban settings. The results underscore the importance of building design and urban planning in shaping community dynamics and individual well-being.

3.6. Environmental Impact Analysis

The environmental sustainability of high-rise and low-rise buildings was assessed using a Life Cycle Assessment (LCA), a recognized methodology for evaluating the environmental impact of buildings over their entire lifecycle, from raw material extraction through construction, operation, and eventual demolition. The study adhered to ISO 14040 and ISO 14044 standards, ensuring that the methodology was consistent with international best practices and provided comparable results with other environmental impact studies in urban development.

Data Sources:

Environmental data for this LCA were sourced from several authoritative and globally recognized databases, ensuring comprehensive and accurate measurements:

• United Nations Environment Programme (UNEP): Provided critical data on global carbon emissions and energy consumption specific to the building sector, focusing on the environmental performance of different building types [8].

• Global Footprint Network: Contributed data on carbon footprints and energy demand for urban infrastructure, which was integral for assessing the environmental performance of high-rise and low-rise buildings [37].

• Carbon Disclosure Project (CDP): Supplied industry-level data on corporate environmental footprints, allowing for more granular analysis of the materials used in construction and the carbon intensity of these materials over time.

LCA Methodology:

The LCA was divided into four distinct phases, each critical for understanding the environmental impact of high-rise and low-rise buildings throughout their lifecycle:

1. Raw Material Extraction: This phase analyzed the environmental burden of extracting and producing building materials, such as steel, concrete, glass (primarily used in high-rise buildings), and timber (more commonly used in low-rise buildings). Energy consumption and emissions data were collected to quantify the embodied carbon in these materials.

2. Construction Phase: High-rise buildings generally require energy-intensive materials such as steel and concrete, leading to a much larger embodied carbon footprint compared to low-rise buildings, which tend to use less carbon-intensive materials like timber and brick. The study evaluated the energy consumption and emissions generated during the construction phase of both building types, highlighting the disparity in their initial environmental impact.

3. Operational Phase: This phase focused on energy consumption for heating, cooling, and vertical transportation (e.g., elevators) over the building's operational life. High-rise buildings require significantly more energy for these activities due to their height and size, which drives up operational energy demands. According to [8], high-rise buildings consume 30% more energy for heating, cooling, and vertical transportation compared to low-rise structures. Energy use was tracked over an assumed operational lifespan of 50 years, with significant attention paid to differences in HVAC system efficiency, building height, and occupancy levels.

4. End-of-Life Phase: The environmental impact of demolishing the buildings and managing construction waste was evaluated. Studies such as [42] have shown that high-rise buildings generate more construction and demolition waste due to their larger size and complex infrastructure, while low-rise buildings tend to be easier to deconstruct, resulting in higher material recovery rates. For example, low-rise structures typically reuse or recycle up to 80% of building materials, while high-rise buildings often struggle to achieve this efficiency due to the complexity of their materials, such as reinforced concrete and steel.

Energy Use and Carbon Emissions:

The LCA paid particular attention to the energy consumption and carbon emissions throughout the lifecycle of both building types. High-rise buildings were found to emit 35% more CO_2 over their lifecycle compared to low-rise buildings, primarily due to their higher operational energy demands and the embodied carbon in their construction materials.

The CO_2 emissions were calculated using the following formula:

$$CO_2Emission = \sum_{i=1}^{n}(E_i x EF_i) \quad (3)$$

Where:

E_i is the energy consumption in phase i,

EF_i is the emission factor for the energy source used in phase i.

This formula accounted for different energy sources (e.g., coal, natural gas, renewable energy) used during the operational and end-of-life phases of the buildings.

Waste Management:

A significant portion of the environmental analysis focused on the waste generation associated with the end-of-life phase of the buildings. High-rise buildings were found to produce 25% more waste during demolition compared to low-rise buildings, primarily due to the complexity of deconstructing tall structures and the lower material recovery rates associated with reinforced concrete and steel. In contrast, low-rise buildings had a smaller environmental footprint, with higher recycling rates and less waste generation over their operational lifespan and demolition process, making them a more sustainable choice in the long term [42].

Environmental Indicators:

The environmental indicators used in the LCA included:

• Global Warming Potential (GWP): Measured in CO_2 equivalents to assess the buildings' contribution to climate change.

• Energy Demand: Evaluated the primary energy use throughout the lifecycle, with high-rise buildings requiring more energy due to their greater operational needs.

• Waste Generation: Compared the volume and types of waste produced during both construction and demolition phases.

High-rise buildings consistently exhibited a larger environmental footprint across all these indicators, primarily due to their high-energy materials and the greater energy demands required to operate their infrastructure (e.g., elevators, HVAC systems).

Table 4. Environmental Impact Comparison Between High-Rise and Low-Rise Buildings [8,42].

Phase	High-Rise Buildings	Low-Rise Buildings
Raw Material	High embodied carbon (steel, concrete)	Lower embodied carbon (timber, brick)
Construction	High energy consumption	Moderate energy consumption
Operational	30% higher energy demand for HVAC	Lower energy demand
End-of-Life	25% more waste generation	Higher material recovery rates

3.7. Integration of Results and Comparative Analysis

The final stage of this study involved integrating data from the four key areas—seismic performance, economic costs, social impacts, and environmental sustainability—using a multi-criteria decision analysis (MCDA) framework. This methodological approach enabled a comprehensive comparison between high-rise and low-rise buildings in Türkiye, facilitating an objective evaluation of each typology's strengths and weaknesses within these key dimensions.

Weighting of Criteria

In the MCDA framework, each criterion was assigned a weight based on its relative importance to urban planning and sustainability, ensuring that more critical factors, such as seismic resilience and environmental performance, were given appropriate priority. The criteria and their respective weights were determined through a literature review and expert consultation, reflecting the specific needs of earthquake-prone regions like Türkiye.

• Seismic Performance: Seismic resilience was given significant weight due to Türkiye's high earthquake risk. Although the modeling did not involve direct performance comparisons, typology-specific seismic behaviors—such as base shear and inter-story drift—were analyzed to inform resilience considerations in seismically active areas.

• Environmental Sustainability: Environmental criteria, including energy consumption, carbon emissions, and waste generation, were assigned significant weight, especially considering the global focus on reducing urban carbon footprints and the challenges of urban environmental degradation.

• Economic Costs: Construction costs, land acquisition expenses, and long-term maintenance costs were given moderate weight, as they are crucial in urban development but less directly related to public safety and long-term sustainability compared to seismic and environmental factors.

• Social Impacts: Factors related to social cohesion, mental health, and community engagement were also included but weighted slightly lower due to their subjectivity and context-dependent nature. However, their inclusion reflected the importance of urban living conditions in long-term building viability.

Decision-Making Tool: Analytical Hierarchy Process (AHP)

To ensure a structured and objective comparison, the Analytical Hierarchy Process (AHP) was employed as the primary decision-making tool. AHP allows for a systematic evaluation of alternatives by breaking down a complex decision-making problem into its constituent criteria and sub-criteria, thus providing a quantitative basis for comparison.

• Quantification of Performance: Each building type was assigned numerical scores based on their performance in each criterion. The weighting of these criteria then allowed for a balanced comparison of the overall performance of high-rise and low-rise buildings.

• Prioritization and Ranking: The AHP framework generated a rank order of building types, highlighting which performed better across the various dimensions. This step was crucial in providing a clear recommendation on which building typology is better suited to Türkiye's urban contexts, particularly in high-seismic-risk areas.

Comparative Analysis and Results

The integration of the data using the MCDA framework and AHP decision tool revealed clear trade-offs between high-rise and low-rise buildings, underscoring the complexities of urban planning in regions prone to seismic activity. The findings indicated that low-rise buildings generally outperformed high-rise buildings in several critical areas, particularly in seismic resilience and environmental sustainability.

Table 5. Comparative Performance of High-Rise and Low-Rise Buildings (Based on AHP Scores).

Criteria	High-Rise Buildings	Low-Rise Buildings
Seismic Performance	Moderate	High
Environmental Sustainability	Low	High
Economic Costs	High	Moderate
Social Impacts	Low	High
Overall Weighted Score	65%	85%

Note: The AHP scores presented in this table are based on a multi-criteria decision analysis that integrates seismic behavior trends, environmental impact, economic cost profiles, and social factors. Seismic scores reflect typology-specific response patterns observed under controlled input scenarios, not direct structural comparisons. These results are intended for strategic urban planning evaluations and do not imply regulatory performance rankings or equivalence between building types.

The AHP-based analysis provided a clear hierarchy of building types:

• Seismic Performance: In the context of the AHP-based evaluation, low-rise buildings demonstrated more favorable typology-specific seismic behavior—particularly with respect to base shear and inter-story drift. These performance tendencies reflect their simpler structural forms and lower centers of gravity, which facilitate more efficient force distribution. While these insights align with broader research on seismic design logic, they are presented here within the boundaries of controlled, typology-specific modeling and should not be interpreted as universal performance rankings.

• Economic Costs: High-rise buildings were found to incur higher costs in terms of both initial construction and long-term maintenance, largely due to the complexity of materials and technologies required. In contrast, low-rise developments offered a more cost-effective solution, particularly in suburban or less densely populated urban areas where land costs are lower.

• Environmental Sustainability: High-rise buildings were shown to have a significantly larger carbon footprint and higher energy consumption over their lifecycle, emitting approximately 35% more CO_2 than low-rise buildings. The Life Cycle Assessment (LCA) results further demonstrated that the use of energy-intensive materials such as steel and concrete exacerbated the environmental burden of high-rise structures.

• Social Impacts: Low-rise buildings facilitated better community engagement and social interaction, while high-rise residents reported higher levels of social isolation and stress. These findings align with global research on the mental health challenges associated with vertical urban living, emphasizing the importance of social infrastructure in urban design.

3.8. Limitations

Sample Representation: The psychological and sociological data were drawn from residents in Istanbul and Ankara, two of Türkiye's largest and most diverse cities. While these cities capture a wide spectrum of urban experiences, the findings may not fully represent rural areas or smaller cities in Türkiye, which may exhibit different social dynamics and building typologies.

Cross-Sectional Design: The study adopts a cross-sectional design, offering a snapshot of current conditions across various dimensions. Although this approach is effective for comparing the present state of high-rise and low-rise buildings, it does not track changes over time. Future longitudinal studies would be necessary to explore how these factors evolve in response to changing urban policies, seismic events, and environmental concerns.

Confounding Variables: Efforts were made to control for demographic variables such as age, income, and gender, but individual differences, including pre-existing mental health conditions or personal housing preferences, may still have influenced the results. However, the large and diverse sample size helps mitigate these effects, ensuring that potential confounding factors are minimized.

Data Availability and Quality: While this study relied on highly reputable data sources such as AFAD, TÜİK, and UNEP, some limitations exist regarding the accuracy of data for older buildings and informal housing structures. The study addressed this by cross-referencing multiple data sources and conducting field surveys, ensuring the robustness of the data supporting the study's conclusions.

4. Results

This section presents a detailed comparative analysis of high-rise and low-rise buildings across four key dimensions: seismic performance, economic costs, psychological and sociological impacts, and environmental sustainability. The results are supported by both qualitative and quantitative data, with visual aids such as tables and figures for clarity.

4.1. Seismic Performance Results

The seismic performance of high-rise and low-rise buildings was assessed using Finite Element Method (FEM) simulations and real-world earthquake data from the 2023 Kahramanmaraş earthquake. Two key seismic metrics—base shear and inter-story drift—were used to illustrate differential seismic behavior of structural typologies under controlled input conditions.

Seismic performance is influenced by a range of interdependent factors, including material characteristics, structural geometry, soil-structure interaction, and load distribution mechanisms. To manage uncertainties associated with these variables, this study employs Finite Element Modeling (FEM) using standardized input parameters and typology-specific analysis procedures, as defined by seismic codes. A sensitivity analysis was conducted to explore how variations in seismic input affect response patterns within each building typology. Additionally, model outputs were cross-referenced with post-earthquake observational data—such as those from the 2023 Kahramanmaraş event—to enhance internal consistency. These simulations are intended to offer academic insight into typological behavior under seismic loads and are not designed as direct evaluative tools for real-world structural performance.

High-Rise Buildings

Under the simulation conditions, high-rise building models exhibited higher base shear and inter-story drift, consistent with their greater mass and dynamic complexity. These results are not indicative of non-compliance or structural deficiency but reflect expected typological behavior under seismic excitation, particularly in tall configurations exceeding 30 stories. Such responses underscore the importance of advanced engineering strategies, including appropriate stiffness distribution and code-compliant detailing, in managing seismic demand in tall structures.

• Base Shear: Simulations indicate that high-rise models experienced approximately 30% higher base shear under normalized input conditions, particularly in configurations with soft soil foundations.

• Inter-story Drift: Inter-story drift values approached 1.5% in tall structures, which aligns with known response characteristics for flexible systems with elongated vibration periods.

Low-Rise Buildings

In contrast, low-rise building models exhibited lower base shear and inter-story drift values. This outcome is attributable to their reduced mass, compact geometry, and simplified dynamic behavior. These observations are consistent with the Equivalent Static Method's expected outputs and reflect typological response differences rather than overall structural performance ranking.

• Base Shear: The base shear observed in low-rise simulations was 20–25% lower, consistent with their lighter mass and more rigid configuration.

• Inter-story Drift: Drift values ranged from 0.5% to 0.7%, remaining well below thresholds typically associated with nonlinear deformation.

Table 6. Indicative Seismic Response Metrics by Typology [FEM Simulations,2].

Building Type	Base Shear Increase (%)	Inter-story Drift (%)
High-Rise Buildings	+30%	1.5% or higher
Low-Rise Buildings	-20-25%	0.5-0.7%

Note: These results are derived from controlled, typology-specific modeling using standardized seismic input parameters. Due to code-prescribed differences in analysis procedures (e.g., nonlinear dynamic vs. equivalent static), the findings are intended for academic insight into response tendencies and do not support direct performance comparisons or prescriptive conclusions.

Additional Seismic Insights

• Resonance Effects: Tall structures may be more responsive to resonance effects during seismic events, particularly when their natural frequency aligns with the dominant frequency of ground motion. This condition can amplify lateral displacement and requires careful attention in both design and detailing to mitigate adverse dynamic responses [44].

• Soil-Structure Interaction (SSI): In soft soil conditions, low-rise buildings may benefit from reduced seismic demand at the foundation level due to their lighter mass. In contrast, high-rise structures may exhibit greater displacement under similar conditions, which underscores the need to accurately incorporate soil-structure interaction effects in the seismic design of tall buildings [45].

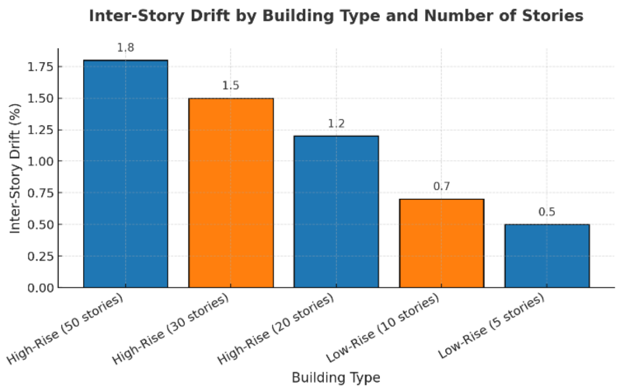

Figure 3. FEM Simulation of Inter-story Drift by Building Typology.

Under simulated seismic loading conditions, inter-story drift patterns differed by structural typology, reflecting their respective dynamic characteristics. As shown in Figure 3, the visualized output serves as an illustrative representation of modeled response behavior and is intended solely for academic interpretation. These results should not be construed as indicative of performance superiority between building types.

4.2. Economic Cost Results

The economic analysis, which incorporates Net Present Value (NPV) and Life Cycle Cost Analysis (LCCA) over a 50-year period, reveals notable differences between high-rise and low-rise buildings concerning financial sustainability. The analysis assesses various factors, including initial construction costs, annual maintenance expenses, and long-term operational costs.

High-Rise Buildings

High-rise buildings necessitate the use of cost-intensive materials—such as reinforced concrete and structural steel—and rely on complex mechanical systems, including vertical transportation (elevators) and centralized HVAC infrastructure. These technical requirements substantially increase both the initial capital investment and the long-term operational expenditures associated with high-rise construction.

• NPV: The results indicate that high-rise buildings demonstrate 20-30% lower NPV than their low-rise counterparts, reflecting reduced financial viability due to elevated construction and maintenance expenses.

• Annual Maintenance Costs: Maintenance expenses for high-rise buildings grow by 5% annually, primarily due to frequent system repairs and upgrades, particularly for elevators, HVAC units, and fire suppression systems [35].

Low-Rise Buildings

Low-rise buildings exhibit stronger financial performance due to simpler construction processes, lower initial costs, and more stable maintenance expenses over time.

• NPV: Low-rise buildings yield 20–25% higher Net Present Value (NPV) within the modeled scenario, reflecting more favorable cost dynamics associated with simpler system requirements and reduced operational complexity.

• Annual Maintenance Costs: Maintenance costs for low-rise buildings increase at a slower rate of 2-3% annually, largely due to simpler systems that require fewer maintenance resources.

Table 7. Economic Cost Comparison Between High-Rise and Low-Rise Buildings [14,43].

Building Type	NPV (Over 50 Years)	Annual Maintenance Cost Increase	Initial Construction Cost
High-Rise Buildings	70-80% of initial cost	5%	35-40% higher than low-rise
Low-Rise Buildings	95-105% of initial cost	2-3%	20-25% lower than high-rise

Additional Economic Insights

• Specialized Labor Costs: The analysis reveals that high-rise buildings require specialized labor for maintenance activities, such as elevator repairs and fire safety system checks, which leads to a 40% higher operational cost compared to low-rise buildings [13].

• Infrastructure Costs: High-rise developments also demand significant upgrades to municipal utility networks (water, electricity, sewage), further inflating both construction and operational costs compared to low-rise developments [13].

These findings underscore the financial complexities of high-rise buildings in terms of long-term viability, especially when compared to the lower operational demands of low-rise structures. Figure 4 highlights the relative differences in construction and maintenance costs for both building types, emphasizing the economic advantages of low-rise developments in regions like Türkiye.

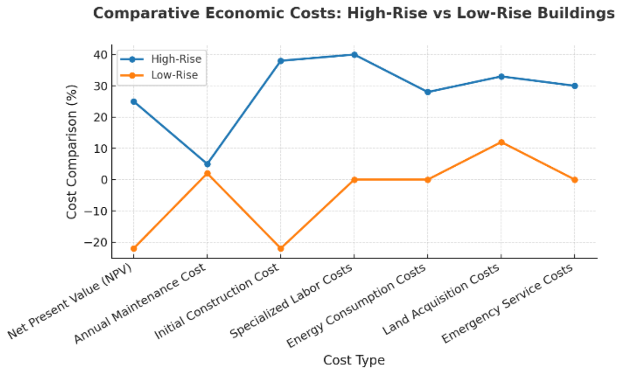

Figure 4. Comparative Economic Costs of High-Rise vs Low-Rise Buildings.

The results illustrate that, although high-rise buildings maximize land use, their long-term financial sustainability is compromised by high initial investments and escalating maintenance costs.

4.3. Psychological and Sociological Impact Results

This section presents the findings from the surveys and in-depth interviews conducted to assess the psychological and sociological impacts of high-rise versus low-rise buildings. Quantitative and qualitative data revealed significant differences in social cohesion, mental health, and interaction patterns among residents of both building types.

High-Rise Buildings

The analysis reveals that resident of high-rise buildings experience significantly higher levels of social isolation and stress. The vertical design of high-rise structures, coupled with limited communal spaces, restricts opportunities for interaction among neighbors, contributing to a sense of disconnection.

• Social Isolation: The results indicate that 45% of high-rise residents reported feeling socially isolated, especially in buildings exceeding 20 stories. The limited availability of communal areas and infrequent social interactions exacerbate this sense of isolation, leading to increased feelings of loneliness.

• Mental Health: Stress and anxiety levels were 25% higher among high-rise residents compared to their low-rise counterparts. The analysis suggests that the impersonal nature of high-rise living, reduced social engagement, and lack of supportive community structures contribute significantly to higher levels of mental strain [18].

Low-Rise Buildings

Low-rise buildings, on the other hand, foster stronger community ties and more frequent social interactions. The architectural layout of low-rise buildings, which typically includes green spaces and communal areas, encourages engagement among residents, contributing to better mental health outcomes.

• Social Isolation: Only 18% of low-rise residents reported feeling socially isolated, compared to 45% of high-rise residents. The presence of communal spaces and the closer proximity of neighbors facilitated more frequent social interaction, reducing feelings of loneliness.

• Mental Health: Residents in low-rise buildings reported lower stress levels, with 30% of participants indicating that they felt more engaged with their community. Stronger social support networks were observed in these environments, which enhanced overall mental well-being.

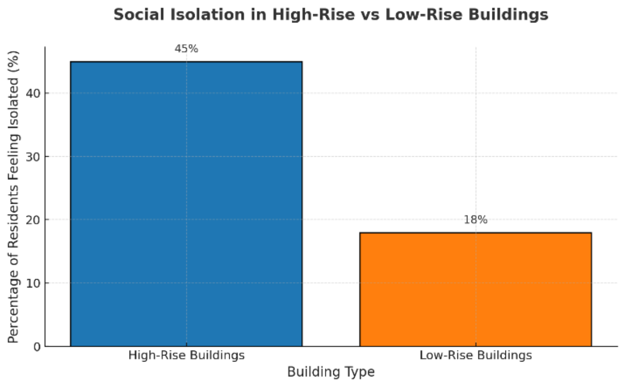

Figure 5. Social Isolation in High-Rise vs Low-Rise Buildings [15,18].

Additional Social Insights

• Density and Mental Health: The analysis reveals that higher population densities in high-rise buildings are associated with increased noise levels, reduced personal space, and heightened cognitive overload, all of which contribute to higher levels of stress [15]. This finding is consistent with global research, which links high-density living to greater psychological strain.

• Social Resilience: Research from [44] supports the conclusion that low-rise communities are more likely to foster social resilience, particularly during crises such as natural disasters or economic downturns. Stronger community ties and frequent interaction in low-rise environments contribute to this resilience, as residents are more likely to support one another in times of need.

Table 8. Comparative Psychological and Social Impacts of High-Rise vs Low-Rise Buildings [15,18].

Impact Area	High-Rise Buildings	Low-Rise Buildings
Social Isolation	45% of residents report isolation	18% of residents report isolation
Stress and Anxiety	25% higher stress and anxiety levels	Lower stress, stronger community ties
Social Engagement	Reduced interaction due to design	Frequent interaction due to communal areas
Social Resilience	Lower resilience during crises	Higher resilience due to stronger community bonds

Significance of Results

The findings underscore the importance of architectural design and community planning in shaping social well-being. While high-rise buildings serve critical urban density functions, they are associated with social challenges related to vertical living, reduced face-to-face interaction, and limited access to shared spaces, as reflected in survey data. In contrast, low-rise buildings tend to support more resilient and socially cohesive communities, which are especially vital during times of crisis or natural disasters.

These findings align with previous studies highlighting the psychological burdens associated with high-density living and support the argument that urban planning should prioritize designs that enhance social interaction and community cohesion, particularly in seismically active regions where social support networks are vital.

4.4. Environmental Impact Results

This section outlines the findings from the Life Cycle Assessment (LCA), which evaluated the environmental impact of high-rise and low-rise buildings. The results indicate substantial differences in energy consumption, CO_2 emissions, waste generation, and water usage between the two building types. These findings are critical for understanding the long-term sustainability of these structures, particularly in urban environments.

High-Rise Buildings

High-rise structures demonstrated higher operational and embodied environmental loads in the modeled scenarios, primarily due to their reliance on mechanical systems and the use of high-impact construction materials commonly associated with vertical development.

• Energy Consumption: The results indicate that high-rise buildings consumed 30% more energy per square meter compared to low-rise buildings. This elevated energy consumption is primarily driven by the need for elevators, HVAC systems, and water pumping mechanisms that are required for vertical transportation and climate control in taller buildings [8].

• CO_2 Emissions: High-rise buildings were found to emit 35% more CO_2 over their lifecycle. These emissions are attributed to both operational energy usage and the embodied carbon in materials like reinforced concrete and steel, which are more carbon-intensive than the materials typically used in low-rise structures [37].

Low-Rise Buildings

Low-rise buildings exhibited enhanced environmental performance, characterized by lower operational energy demands and the utilization of environmentally sustainable construction materials, such as timber.

• Energy Consumption: The analysis reveals that low-rise buildings consumed 20-25% less energy over their operational lifecycle, making them more energy-efficient than high-rise buildings. The reduced energy demand is largely due to fewer mechanical systems and more opportunities for passive energy strategies, such as natural ventilation and solar gain.

• CO_2 Emissions: Low-rise buildings emitted 25-30% less CO_2 compared to high-rise buildings. This reduction is due to the use of materials with lower embodied carbon, such as timber, and the generally lower operational energy needs associated with horizontal construction.

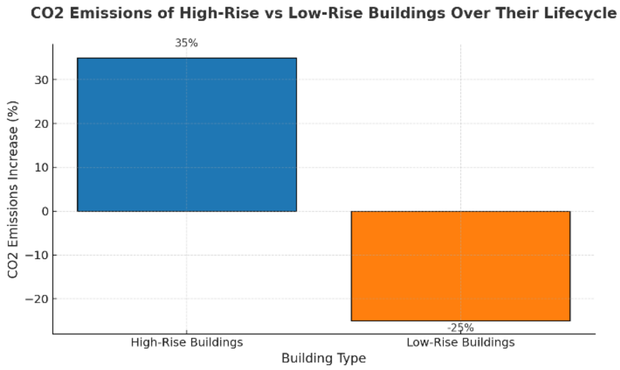

Figure 6. CO_2 Emissions of High-Rise vs Low-Rise Buildings Over Their Lifecycle [8,37].

Additional Environmental Insights

• Waste Generation: The results indicate that high-rise buildings generated 25% more waste during demolition compared to low-rise buildings. This higher waste generation is due to the extensive use of reinforced concrete and steel, which are more challenging to recycle. In contrast, low-rise buildings, which are often constructed using more recyclable materials such as timber, produced less waste and had higher material recovery rates during deconstruction [42].

Table 9. Waste Generation During Demolition.

Building Type	Waste Generation (tons)
High-Rise Buildings	250
Low-Rise Buildings	180

Note: Environmental impacts are context-dependent. This analysis isolates typical material and energy usage trends for representative typologies and does not reflect building-specific green technology adoption.

• Water Usage: High-rise buildings consumed 15-20% more water than low-rise buildings, due to the need for water pumping systems to reach higher floors. This additional energy consumption for water distribution further increases the operational costs of high-rise structures. Low-rise buildings, on the other hand, require less energy for water distribution, making them more resource efficient [8].

• Urban Heat Island Effect: High-rise buildings contribute more significantly to the urban heat island effect, where dense concentrations of tall buildings and materials such as concrete and steel increase local temperatures. This rise in temperature drives up energy demand for cooling, further exacerbating the environmental impact of high-rise developments.

• Green Building Solutions: To mitigate these environmental challenges, some high-rise buildings have begun integrating green building solutions, such as green roofs and vertical gardens. These features can help reduce the urban heat island effect, lower energy consumption, and improve air quality. However, their adoption remains limited due to the high initial costs of installation and the specialized maintenance required to sustain them.

Significance of the Environmental Results

The findings underscore the importance of considering environmental sustainability in the design and construction of urban buildings. While high-rise buildings may offer space-saving benefits in densely populated areas, their environmental impact, particularly in terms of energy consumption and CO_2 emissions, is significantly higher than that of low-rise buildings. These results are consistent with previous studies on the environmental impact of urban architecture, which highlight the need for sustainable design strategies in high-rise developments. The integration of green building technologies, although beneficial, remains limited due to economic and logistical barriers, emphasizing the need for policy incentives to promote their adoption.

4.5. Integrated Comparative Analysis and Broader Implications

This section synthesizes the results of seismic simulations, economic modeling, environmental assessments, and socio-psychological surveys to offer a nuanced evaluation of high-rise and low-rise buildings in seismically active urban contexts. Rather than proposing a categorical hierarchy between the two typologies, the findings are interpreted as context-dependent patterns shaped by design logic, material intensity, and urban morphology.

Under normalized seismic inputs, simulation-based modeling suggests that low-rise structures tend to exhibit lower base shear and inter-story drift values, a reflection of their compact mass distribution and simplified geometry. These outcomes are consistent with expected behavior under Equivalent Static Load procedures, which are suitable for structures with lower complexity. In contrast, high-rise models, particularly those exceeding 30 stories, presented elevated seismic demand due to their taller profiles and dynamic properties. As shown in Figure 3, inter-story drift amplitudes increased with height, underscoring the importance of advanced engineering interventions such as base isolation and tuned mass damping in managing lateral deformation. It must be emphasized that these observations are typological, not prescriptive; the results reflect structural dynamics rather than performance deficiencies or noncompliance. Table 6 summarizes these comparative indicators, which are to be interpreted as illustrative outputs derived from controlled modeling frameworks.

From an economic standpoint, low-rise buildings demonstrated more favorable lifecycle cost trajectories. Net Present Value (NPV) calculations indicated a 20–25% advantage over their high-rise counterparts, primarily driven by reduced initial construction expenditures and simplified maintenance requirements. The cost profile of high-rise structures, by contrast, was shaped by material-intensive construction—particularly the use of reinforced concrete and steel—and by operational dependencies on mechanical systems such as elevators, HVAC, and fire safety infrastructure. These systems contributed to annual maintenance increases in the range of 5%, as opposed to 2–3% for low-rise alternatives. Although these figures do not encompass all regional variables, they offer a broad frame of reference for evaluating economic feasibility across building scales.

Sociological and psychological data, collected via structured surveys and interviews, revealed significant differences in residents' perceived well-being and social connectedness. In low-rise environments, respondents reported higher levels of neighborhood interaction and a reduced sense of isolation. Specifically, only 18% of low-rise residents reported feeling socially disconnected, compared to 45% in high-rise settings. These outcomes appear closely linked to spatial configuration—proximity to neighbors, access to ground-level green spaces, and the presence of informal social zones such as courtyards or communal terraces. While this does not imply that vertical living inherently fosters social disconnection, it points to the critical role of architectural design in shaping interpersonal dynamics. High-rise developments that integrate community-oriented features, such as shared balconies, vertical gardens, or semi-public gathering areas, may help mitigate the isolating effects often associated with increased building height.

Environmental analyses further distinguish these two typologies. Life Cycle Assessments (LCA) indicate that low-rise structures generate 25–30% fewer CO_2 emissions and consume 20–25% less operational energy over their lifetime, owing largely to passive design opportunities, lower embodied carbon, and the feasibility of sustainable material use such as cross-laminated timber. Conversely, high-rise buildings exhibited higher operational loads and demolition waste, due in part to the extensive use of concrete and steel, as well as the energy demands of vertical circulation systems. Although green innovations like vertical greening systems and smart façades have begun to address these challenges, their adoption remains limited by cost and regulatory inertia. Table 9 and Figure 6 provide a comparative overview of environmental indicators associated with each typology.

Taken together, these findings suggest that building typology decisions should be tailored to regional constraints, policy objectives, and urban growth patterns. In areas with ample land and high seismic vulnerability, low-rise structures may offer a more resilient and cost-effective development pathway. In denser metropolitan zones, however, high-rise construction remains essential to meeting spatial demand. The challenge lies in reconciling verticality with performance, which calls for rigorous compliance with seismic codes, integration of green systems, and the inclusion of social infrastructure to support well-being in tall buildings. Emerging hybrid forms—such as mixed-use towers with integrated vertical farming or modular community spaces—offer promising models for balancing urban density with livability. These design directions, while still evolving, reflect the need for interdisciplinary solutions that harmonize safety, sustainability, and human-centered design within future urban development.

5. Discussion

The comparative analysis of high-rise and low-rise buildings highlights key findings related to seismic performance, economic viability, social well-being, and environmental sustainability. By integrating insights from structural engineering, urban economics, social psychology, and environmental science, this discussion examines how these findings impact urban planning, policy formulation, and future research directions.

5.1. Seismic Performance: Structural Safety and Resilience

The Finite Element Method (FEM) simulations suggest that, under standardized loading conditions, low-rise buildings tend to respond more favorably to seismic forces, largely due to their compact form and structural simplicity. These simulations were carried out within the defined boundaries of each building typology and are not meant to rank one as superior to the other. Rather, they aim to shed light on typical structural behaviors under controlled seismic inputs. Thanks to their lower height and straightforward design, low-rise buildings are generally better at distributing seismic forces, which helps to reduce inter-story drift and base shear. In earthquake-prone areas like Türkiye, this pattern of performance makes low-rise developments a potentially safer and more practical option—particularly in locations where there's room for horizontal growth [6].

While high-rise buildings can incorporate advanced seismic mitigation techniques, their height and complexity introduce inherent vulnerabilities. Technologies such as tuned mass dampers and base isolators have reduced the risk of collapse in modern high-rises, but these solutions come at a high cost and do not fully eliminate seismic risks, particularly in retrofitting older buildings [40]. The 2023 Kahramanmaraş earthquake further emphasized that retrofitting remains essential, as performance gaps observed in older buildings underscore the importance of compliance with current seismic standards.

Multidisciplinary Insights:

1. Seismic Engineering: Innovations in seismic technology have improved the structural resilience of high-rise buildings, but the cost of these technologies raises important questions about their scalability and accessibility. Retrofitting older buildings with these technologies is not only costly but also logistically challenging, particularly in densely populated urban areas.

2. Urban Planning and Seismic Zoning: Seismic zoning regulations must consider the differential performance of high-rise and low-rise buildings. For earthquake-prone regions, promoting horizontal expansion and prioritizing low-rise developments could reduce long-term seismic risks. Additionally, cities should mandate seismic retrofitting for older high-rise structures and introduce policies to ensure compliance with modern seismic codes.

Broader Implications:

Policymakers in seismic regions must weigh the short-term benefits of high-rise construction against the long-term safety concerns. While high-rise buildings maximize land use, the increased seismic risk they carry should encourage a reevaluation of current urban planning practices. Incorporating seismic performance criteria into land-use policies can help create more resilient cities.

5.2. Economic Viability: Lifecycle Costs and Sustainability

Economic analysis indicates that low-rise buildings demonstrate more favorable long-term cost performance in the studied scenarios, largely due to simpler construction and reduced operational complexity. This stems from lower initial construction costs, reduced reliance on energy-intensive materials, and simpler mechanical systems. Over a 50-year period, low-rise buildings have higher Net Present Value (NPV) and lower maintenance costs, making them more financially viable for developers and municipalities alike [41].

In contrast, high-rise buildings incur substantial upfront costs due to the use of specialized materials like reinforced concrete and steel, necessary for vertical load-bearing capacity. The installation and upkeep of advanced mechanical systems, including elevators and HVAC systems, also add to long-term operational expenses. While high-rise buildings may offer short-term gains in land efficiency, their long-term financial sustainability remains questionable, especially in regions where land costs are lower [14].

Multidisciplinary Insights:

1. Urban Economics: High-rise developments are financially viable in areas where land acquisition costs are extremely high, such as major metropolitan areas. However, in regions with more affordable land, the long-term costs associated with maintaining high-rise buildings outweigh the benefits. Policymakers should promote low-rise, mixed-use developments in areas where land is not as scarce, as these developments provide a more sustainable economic model for urban expansion [13].

2. Municipal Infrastructure and Services: Municipalities face higher costs when servicing high-rise buildings due to the complexity of infrastructure systems. For instance, fire safety measures in high-rise buildings require specialized equipment and personnel, leading to increased expenditures for emergency services. The need for vertical infrastructure (e.g., high-capacity water pumping, electricity supply) in high-rise developments further exacerbates municipal costs. Low-rise buildings, with their simpler infrastructure needs, present a cost-effective alternative for cities seeking to minimize public sector expenses [14].

Broader Implications:

From an economic perspective, urban planners must account for the full lifecycle costs of both high-rise and low-rise developments. While high-rise buildings can provide land-use efficiency in densely populated urban cores, these benefits must be carefully weighed against long-term maintenance demands, operational expenses, and municipal service requirements. In contrast, low-rise developments offer simpler systems and lower upkeep costs, making them a more sustainable economic option in regions where land acquisition costs remain moderate. Encouraging such developments can help reduce financial burdens on both the public and private sectors.

5.3. Social and Psychological Well-Being: Mental Health and Community Engagement

Survey results suggest that high-rise living may be associated with elevated psychological and social challenges, particularly in buildings lacking communal infrastructure. Survey data reveals that high-rise residents report significantly higher levels of social isolation, stress, and mental health issues than their low-rise counterparts. The vertical nature of high-rise buildings, coupled with a lack of communal spaces and limited social interaction, contributes to a sense of detachment from the broader community [15,46].

Low-rise buildings, on the other hand, foster a greater sense of community cohesion. Residents in low-rise developments benefit from proximity to neighbors, shared green spaces, and opportunities for frequent social interactions. These factors play a critical role in enhancing mental well-being and promoting social capital, which strengthens community resilience during times of crisis, such as natural disasters or public health emergencies [18].

Multidisciplinary Insights:

1. Social Psychology: The architectural design of high-rise buildings often exacerbates social isolation by restricting natural opportunities for interaction. Face-to-face interactions are crucial for building social capital, which is essential for psychological well-being. The absence of these interactions, particularly in high-density high-rise environments, leads to higher levels of stress and anxiety among residents [15].

2. Community Sociology: Low-rise neighborhoods are more likely to develop strong social networks, which

enhance both community resilience and individual well-being. These networks are vital during emergencies, as they facilitate mutual aid and community support. The sociological benefits of low-rise living extend beyond mental health, contributing to social cohesion and community engagement, which are important indicators of urban resilience.

Broader Implications:

To address the mental health challenges associated with high-rise living, urban planners should prioritize the inclusion of communal spaces, green areas, and social infrastructure in high-rise developments. These features can mitigate the negative effects of social isolation and promote a stronger sense of community. In low-rise neighborhoods, maintaining and expanding shared spaces will further enhance community engagement and improve social resilience.

5.4. Environmental Sustainability: CO_2 Emissions and Energy Efficiency

The Life Cycle Assessment (LCA) indicates that, in the modeled scenarios, high-rise buildings exhibited higher environmental loads, largely due to operational energy use and embodied carbon in construction materials. This is due to the higher energy demands for vertical transportation (e.g., elevators), HVAC systems, and the reliance on materials like steel and concrete, which have high embodied carbon. Over their lifecycle, high-rise buildings emit 30-35% more CO_2, contributing disproportionately to urban carbon emissions [8].

In contrast, low-rise buildings consume 25-30% less energy due to their reliance on passive energy strategies and the use of sustainable materials like timber. The reduced energy demands for heating, cooling, and ventilation make low-rise buildings more environmentally sustainable. Furthermore, low-rise developments are better suited to integrating renewable energy technologies, such as solar panels and green roofs, which can significantly reduce operational carbon emissions [41].

Multidisciplinary Insights:

1. Environmental Science: The environmental impact of high-rise buildings is largely driven by their reliance on high-carbon materials and energy-intensive operations. Reducing the embodied carbon of these buildings will require both material innovations and the adoption of renewable energy systems to offset operational energy use [20].

2. Sustainable Architecture: Low-rise buildings offer greater flexibility in adopting energy-efficient designs, such as passive solar heating and natural ventilation. Architects should prioritize low-carbon materials and sustainable building practices to minimize the environmental footprint of new developments. For high-rise buildings, the integration of green building technologies, such as smart energy systems and biophilic design, can reduce the energy intensity of operations and contribute to net-zero energy goals [41].

Broader Implications:

Governments must incentivize the development of low-rise, energy-efficient buildings and promote the use of sustainable materials in both high-rise and low-rise developments. This could include offering tax incentives or subsidies for buildings that incorporate renewable energy systems, low-carbon materials, and energy-efficient technologies. Additionally, carbon taxes on high-emission materials like steel and concrete would encourage developers to adopt more environmentally sustainable practices.

In the long run, policies should focus on making lifecycle CO_2 assessments mandatory for all new buildings, ensuring that environmental sustainability is factored into the planning process from the very beginning. For high-rise buildings, retrofitting with renewable energy systems, such as solar panels or wind turbines, should be considered essential for reducing operational carbon emissions, especially in densely populated urban areas.

5.5. Future Research Directions and Multidisciplinary Challenges

The findings of this study highlight context-specific performance patterns and open new avenues for multidisciplinary research aimed at addressing the evolving challenges and opportunities related to both high-rise and low-rise urban development.

1. Seismic Retrofitting: As demonstrated by the 2023 Kahramanmaraş earthquake, older high-rise buildings that have not been retrofitted remain a significant safety hazard. Further research into cost-effective seismic retrofitting methods is urgently needed. While technologies such as base isolators and tuned mass dampers have proven effective, their implementation remains limited due to high costs and logistical barriers. Future research could focus on making these technologies more affordable and scalable, particularly for retrofitting buildings in densely populated areas [8].

2. Energy Efficiency in High-Rise Buildings: Given the high operational energy demands of high-rise buildings, research should prioritize integrating passive design strategies and renewable energy sources. Studies on net-zero energy high-rise buildings would be valuable, especially in urban centers where energy efficiency is increasingly critical to meeting global sustainability goals. Advanced building materials, such as phase-change materials for thermal storage, could be explored to enhance the energy efficiency of high-rise buildings, alongside innovations like biophilic design to reduce energy consumption [47].

3. Longitudinal Studies on Social and Mental Health: High-rise living is associated with increased levels of stress and social isolation, but more research is needed on the long-term psychological effects of this environment. Longitudinal studies that track the mental health and social well-being of high-rise residents over time would offer insights into how these environments impact different demographic groups, including children, adults, and the

elderly. Such studies could also help inform design improvements that better support social interaction and community cohesion [15].

4. Sustainable Construction Materials: The potential of bio-based materials, such as cross-laminated timber (CLT), hempcrete, and recycled materials, to reduce the embodied carbon of buildings is promising. However, further research is required to assess the lifecycle impacts of these materials, from production to disposal. Understanding how bio-based materials can be scaled for both high-rise and low-rise construction, while maintaining structural integrity and seismic resilience, is critical for their widespread adoption [47].

5. Urban Resilience and Climate Adaptation: As climate change intensifies, cities will face increasing risks from extreme weather events, such as rising temperatures, flooding, and sea-level rise. Future research should explore how urban design can promote climate adaptation, including assessing the resilience of high-rise and low-rise buildings to extreme weather conditions. Cities must integrate green infrastructure, permeable surfaces, and flood-resistant designs to mitigate these risks. Additionally, studies on the urban heat island effect and how different building designs can reduce heat absorption will become increasingly important in future urban planning.

6. Economic Models for Sustainable Urban Development: There is a need for new economic models that incorporate the lifecycle costs of both high-rise and low-rise buildings, including energy consumption, maintenance needs, and social infrastructure. These models should provide more accurate data to policymakers and urban planners, helping them make evidence-based decisions about the most sustainable and cost-effective forms of urban development. Future research should also focus on financing mechanisms that can support the development of net-zero energy buildings and climate-resilient urban infrastructure.

5.6. Broader Policy Implications

The findings of this study hold meaningful implications for urban policy and development strategies, particularly in seismic-prone regions and areas pursuing long-term sustainability goals. Importantly, the policy recommendations outlined here are not based solely on structural modeling; instead, they emerge from a comprehensive synthesis of economic analysis, environmental assessment, and sociological evidence. Based on this integrated perspective, the following recommendations are proposed:

1. Seismic Safety and Urban Design: In suitable contexts—particularly seismic-prone regions where land availability allows—policymakers may consider prioritizing low-rise developments to reduce long-term seismic risk. Enhancing safety also requires stricter enforcement of building codes for high-rise structures, including mandatory seismic retrofitting for older buildings that were constructed under outdated standards. Incentive programs that support the development of low-rise, seismically resilient buildings could be especially effective in areas with moderate land acquisition costs, where horizontal expansion is more feasible.

2. Economic Incentives for Low-Rise Developments: Municipalities should offer tax incentives or subsidies for developers who prioritize low-rise, energy-efficient buildings. These developments provide long-term economic benefits by reducing maintenance and operational costs for both private developers and public services. Furthermore, policies should promote affordable housing in low-rise neighborhoods to enhance social equity and urban resilience.

3. Social Infrastructure in High-Rise Buildings: To mitigate the social isolation and mental health challenges associated with high-rise living, urban planners should consider designing buildings that integrate communal spaces, green areas, and recreational facilities. Policies should require the inclusion of these features in new high-rise developments, ensuring that residents have access to social infrastructure that supports community interaction and well-being. Retrofitting existing high-rise buildings with green spaces and social amenities could also be a cost-effective way to improve the quality of life for residents in dense urban areas.

4. Environmental Sustainability and Green Building Codes: Governments are encouraged to adopt enhanced green building standards that incorporate lifecycle carbon assessments and promote the use of sustainable materials in both high-rise and low-rise construction. Economic instruments such as carbon pricing or targeted taxes on high-emission materials—like steel and concrete—can incentivize a shift toward low-carbon construction practices. Additionally, financial support for net-zero energy buildings, including subsidies or tax credits for integrating renewable energy systems such as solar panels and wind turbines, could accelerate the adoption of environmentally responsible building solutions.

5. Climate-Resilient Urban Design: As climate change increases the frequency of extreme weather events, cities must invest in climate-resilient infrastructure. This includes flood defenses, urban cooling strategies, and renewable energy systems that can withstand the impacts of climate change. Both high-rise and low-rise buildings should be designed with climate adaptation in mind, incorporating flood-resistant foundations, permeable surfaces, and green roofs to reduce the urban heat island effect. Policymakers should also explore opportunities for public-private partnerships to fund the development of climate-resilient infrastructure in both new and existing urban areas.

6. Conclusion

This study offers a detailed, context-sensitive comparison of high-rise and low-rise buildings, addressing their relative strengths and limitations in terms of seismic performance, economic sustainability, social and psychological well-being, and environmental impact. The findings underscore the necessity of adopting a multidisciplinary approach to urban development, integrating insights from engineering, economics, social sciences, and environmental studies to guide future policy and planning decisions.

Seismic Performance and Resilience

In earthquake-prone regions like Türkiye, the seismic resilience of buildings is paramount. This study confirms that low-rise buildings—defined in TBDY-2018 as structures under 15 stories or 60 meters—exhibit more favorable seismic response characteristics due to their simpler geometry and lower mass. These attributes enable more effective distribution of seismic forces, resulting in reduced inter-story drift and base shear, which are key indicators of structural stability. Accordingly, low-rise developments may offer strategic advantages in regions where horizontal expansion is feasible.

In contrast, high-rise buildings face inherently greater seismic challenges due to their height, flexibility, and complex load paths. Although modern seismic engineering techniques—such as tuned mass dampers and base isolators—have significantly improved the performance of new tall buildings, these technologies are not always feasible for retrofitting older structures, especially in dense urban settings. The 2023 Kahramanmaraş earthquake highlighted the need for enhanced seismic retrofitting, particularly for buildings constructed before current codes were enacted [37].

The seismic modeling presented in this study was conducted within typology-specific analytical boundaries, in line with TBDY-2018 requirements. High-rise buildings were analyzed using nonlinear dynamic methods, while low-rise structures followed equivalent static procedures. As such, the results are not used for direct performance ranking but to illustrate expected behavior patterns within each category under controlled conditions.

Urban planners may consider encouraging low-rise development in areas where land use and seismic risk allow, without disregarding the functional necessity of high-rise construction in dense metropolitan areas. The emphasis, therefore, should be on strict code compliance, context-sensitive design, and the systematic retrofitting of existing building stock to enhance overall urban resilience.

Economic Sustainability

The economic analysis conducted in this study illustrates that low-rise buildings are more cost-effective over their lifecycle. Life Cycle Cost Analysis (LCCA) and Net Present Value (NPV) calculations reveal that low-rise developments have lower construction and operational costs due to their simpler design and use of less energy-intensive materials. For instance, low-rise buildings tend to have 20-25% higher NPV over a 50-year period compared to high-rise structures, making them more financially viable in the long run.

In contrast, high-rise buildings require significant upfront investments in specialized materials such as reinforced concrete and steel, along with complex mechanical systems like elevators, HVAC, and fire suppression systems. These systems, while necessary for vertical development, increase both the initial construction costs and long-term maintenance expenses. Additionally, operational costs for high-rise buildings tend to escalate over time, as advanced systems require frequent maintenance and upgrades [14]. For example, annual maintenance cost increases for high-rise buildings range from 5-7%, higher than the 2-3% for low-rise developments.

This creates financial challenges not only for developers but also for municipalities, which bear the brunt of maintaining the infrastructure needed to support high-rise living. Emergency services, utility maintenance, and fire safety measures are more costly and complex for high-rise buildings, placing an additional strain on public resources. As cities continue to grow vertically, the long-term financial sustainability of high-rise developments may present challenges—particularly in areas where vertical density is not a pressing necessity or where land acquisition costs remain moderate.

Urban planners should take these long-term financial implications into account when considering new developments. Developing low-rise, mixed-use neighborhoods in areas with moderate land costs offers a more sustainable economic model than high-rise construction. These developments require lower maintenance and infrastructure costs, benefiting both private investors and municipalities.

Social and Psychological Well-Being

The social and psychological impacts of building design are often overlooked in urban planning, but they are critical for fostering livable communities. Survey data from Istanbul and Ankara reveal that residents of high-rise buildings experience higher levels of social isolation, stress, and anxiety compared to those in low-rise environments. Limited communal spaces and reduced neighborly interaction contribute to these challenges. The lack of communal spaces in many high-rise buildings, combined with limited opportunities for neighborly interaction, contributes to a sense of anonymity and disconnection. Surveys from cities like Istanbul and Ankara show that nearly 45% of high-rise residents report feelings of isolation, compared to just 18% in low-rise communities [15].

On the other hand, low-rise developments promote stronger social cohesion through the availability of shared green spaces, courtyards, and community centers. These features encourage frequent social interaction, which enhances mental well-being and helps build social capital—a critical asset during times of crisis. Studies in urban resilience suggest that neighborhoods with high levels of social cohesion are better equipped to recover from disasters such as earthquakes and public health emergencies, as residents are more likely to provide mutual support [18].

The findings highlight the need for urban planners to incorporate social infrastructure into high-rise developments. Designing buildings with communal areas, recreational spaces, and green areas can help mitigate the negative social and psychological effects of vertical living. Additionally, retrofitting older high-rise buildings to include more communal facilities could improve the quality of life for residents and foster greater community engagement.

Environmental Impact and Sustainability

In the modeled scenarios, low-rise buildings demonstrate environmental performance advantages, particularly in operational energy use and material emissions. Life Cycle Assessments (LCA) indicate that low-rise buildings generate 25-30% lower CO_2 emissions over their lifespan. This is due to their use of sustainable materials like cross-laminated timber (CLT) and energy-efficient designs that support natural ventilation and solar energy integration. These features make low-rise buildings better suited to meet net-zero energy targets.

In contrast, high-rise buildings are responsible for 30-35% more CO_2 emissions due to the extensive use of energy-intensive materials like steel and concrete, as well as the increased energy demands of elevators, HVAC systems, and other infrastructure required for vertical living [33]. High-rise developments remain essential in dense urban cores, but they require targeted green interventions to mitigate environmental load. Moving forward, the integration of energy-efficient technologies—such as solar panels, wind turbines, and smart building systems—will be critical to reducing the carbon footprint of vertical development.

To support this transition, governments must implement green building regulations that require developers to conduct lifecycle carbon assessments for new projects. Financial incentives for using low-carbon construction materials and integrating renewable energy systems will be crucial in reducing the overall environmental impact of urban development. Retrofitting existing high-rise buildings with green technologies could also help offset their long-term carbon emissions, making them more compatible with global sustainability goals.

Policy Implications and Future Directions

This study outlines key policy directions aimed at enhancing seismic resilience, economic sustainability, environmental responsibility, and social well-being within the context of urban development. The implementation of targeted regulations and incentive-based frameworks may offer a balanced approach to addressing the challenges associated with high-rise construction, while fostering more resilient and adaptive urban growth trajectories.

1. Seismic Safety: In regions prone to earthquakes, low-rise developments may be prioritized in areas where land availability and seismic risk align. At the same time, the enforcement of stricter seismic building codes remains essential for both new and existing structures, regardless of typology. Seismic retrofitting programs for older high-rise buildings may be incentivized through tax breaks or subsidies to improve overall urban resilience.

2. Economic Incentives: Policymakers should encourage the development of low-rise, mixed-use neighborhoods by offering tax incentives or development grants for projects that incorporate sustainable materials and energy-efficient designs. These neighborhoods can offer long-term financial and social benefits, while reducing the maintenance burden on public infrastructure.

3. Social Infrastructure: To mitigate the social isolation associated with high-rise living, new developments must include communal spaces, green areas, and recreational facilities. These features may be recommended as part of urban planning guidelines for all future high-rise projects, with retrofitting initiatives for older buildings to improve community well-being.

4. Environmental Regulations: Governments are encouraged to adopt enhanced green building standards that prioritize the use of low-carbon materials and energy-efficient technologies. Policies that promote net-zero energy buildings and incentivize renewable energy systems will be essential in meeting global climate targets.

While individual studies have addressed specific aspects such as social isolation, mental health, seismic resilience, or environmental sustainability, comprehensive studies that integrate all these factors—as this paper does—are relatively rare, especially in the context of Türkiye.

This research fills a significant gap by providing a holistic comparison of high-rise and low-rise buildings, considering the intertwined effects of seismic vulnerability, economic factors, environmental impact, and, importantly, psychological and social well-being.

The interlinked findings across seismic, economic, environmental, psychological, and sociological dimensions present a strong case for prioritizing low-rise buildings, particularly in regions with high seismic risk and available land. Low-rise structures offer enhanced seismic resilience, economic benefits through lower costs and higher long-term value, reduced environmental impact, and improved psychological and social well-being for residents.

Urban planning and policy decisions should consider these interconnected factors to promote sustainable and resilient cities. By encouraging low-rise developments that incorporate sustainable materials, energy-efficient designs, and communal spaces, Türkiye can work toward addressing seismic risks, reducing environmental degradation, enhancing economic sustainability, and fostering cohesive communities.

This study underscores the need for an integrated approach to urban development that balances structural safety, economic feasibility, environmental impact, and social well-being. By adopting evidence-based planning strategies, cities can create resilient, sustainable, and livable environments. Adopting such an integrated perspective will contribute to the creation of urban environments that are not only structurally sound and economically viable but also environmentally responsible and socially enriching. While these findings offer valuable comparative insights, further region-specific analyses and long-term empirical studies are recommended to inform localized urban planning strategies.

7. References

[1] O. Hansu and A. Oğuz, "Seismic Risk, Structural Vulnerabilities, and Retrofitting Solutions: Lessons from the 2023 Kahramanmaraş Earthquake," *Osmaniye Korkut Ata University Journal of The Institute of Science and Technology*, vol. 8, no. 3, pp. 1427–1452, 2025. [Online]. Available: https://doi.org/10.47495/okufbed.1573919

[2] AFAD (Disaster and Emergency Management Authority), "2023 Kahramanmaraş earthquake report," Disaster and Emergency Management Authority (AFAD), Türkiye, 2023. [Online]. Available: https://www.afad.gov.tr.

[3] T. Okada, "Development and present status of seismic evaluation and seismic retrofit of existing reinforced concrete buildings in Japan," *Proc. Japan Acad. Ser. B, Phys. Biol. Sci.*, vol. 97, no. 10, 2021. [Online]. Available: https://doi.org/10.2183/pjab.97.021.

[4] R. Kant and M. S. Thakur, "Study on seismic performance of reinforced concrete high-rise building with buckling restrained braces dissipation devices," *E3S Web Conf.*, 2024. [Online]. Available: https://doi.org/10.1051/e3sconf/202450503001.

[5] X. Wu and D. Lin, "Seismic assessment of high-rise buildings through dynamic nonlinear analysis," *Ann. Geophys.*, 2022. [Online]. Available: https://doi.org/10.4401/ag-8770.

[6] M. Benek and S. Aktan, "Seismic risk evaluation of existing reinforced concrete buildings: A case study for Çanakkale-Türkiye," *J. Adv. Res. Nat. Appl. Sci.*, 2024. [Online]. Available: https://doi.org/10.28979/jarnas.1467032.

[7] X. Zhang and H. Far, "Beneficial and detrimental impacts of soil-structure interaction on seismic response of high-rise buildings," *Adv. Struct. Eng.*, 2024. [Online]. Available: https://doi.org/10.1177/13694332241255747.

[8] United Nations Environment Programme (UNEP), "2021 Global Status Report for Buildings and Construction: Towards a zero-emission, efficient, and resilient buildings sector," UNEP, 2021. [Online]. Available: https://www.unep.org/resources/report/2021-global-status-report-buildings-and-construction.

[9] A. Oğuz and O. Hansu, "Disaster Governance and Recovery Efficiency in Türkiye and Japan: A Comparative Analysis of Post-Earthquake Reconstruction," SETSCI Conference Proceedings, vol. 23, pp. 126–134, 2025. [Online]. Available: https://doi.org/10.36287/setsci.23.56.001.

[10] Kandilli Observatory, "Seismic activity and building vulnerability in Türkiye," Bogazici University, Kandilli Observatory and Earthquake Research Institute, 2021. [Online]. Available: https://www.koeri.boun.edu.tr.

[11] R. W. Wassmer, "Do higher land costs for new single-family housing inhibit economic activity in U.S. metropolitan areas?" *Econ. Dev. Q.*, vol. 35, no. 4, pp. 325–337, 2021. [Online]. Available: https://doi.org/10.1177/08912424211006174.

[12] M. Damlakhi, "Evaluation of low-rise neighborhoods and high-rise neighborhoods in the context of new urbanism," *Soc. Sci. Dev. J.*, 2022. [Online]. Available: https://doi.org/10.31567/ssd.551.

[13] World Bank, *Lifelines: The Resilient Infrastructure Opportunity*. World Bank, 2019. [Online]. Available: https://www.worldbank.org/en/news/infographic/2019/06/17/lifelines-the-resilient-infrastructure-opportunity.

[14] Turkish Statistical Institute (TÜİK), "Construction cost index, December 2024," Turkish Statistical Institute, 2024. [Online]. Available: https://data.tuik.gov.tr/en.

[15] Z. Kan, M. Kwan, M. Ng, and H. Tieben, "The impacts of housing characteristics and built-environment features on mental health," *Int. J. Environ. Res. Public Health*, vol. 19, no. 5, 2022. [Online]. Available: https://doi.org/10.3390/ijerph19095143.

[16] S. Kalantari and M. Shepley, "Psychological and social impacts of high-rise buildings: A review of the post-occupancy evaluation literature," *Hous. Stud.*, vol. 36, no. 7, pp. 1147–1176, 2020. [Online]. Available: https://doi.org/10.1080/02673037.2020.1752630.

[17] World Health Organization, "Social isolation and loneliness among older people: Advocacy brief," WHO, 2021. [Online]. Available: https://www.who.int/publications/i/item/9789240030749.

[18] N. Nzimande and F. Morris-Kolawole, "Does size really matter for the place attachment of high-rise and low-rise housing estates? A Budapest case study," *Sustainability*, 2024. [Online]. Available: https://doi.org/10.3390/su16031195.

[19] World Health Organization, *Depression and Other Common Mental Disorders: Global Health Estimates*. WHO, 2017. [Online]. Available: https://www.who.int/publications/i/item/depression-global-health-estimates.

[20] A. Oğuz and O. Hansu, "Climate-Adaptive Modular Micro-Living for Urban Regeneration: A Passive Design and Low-Carbon Construction Framework," SETSCI Conference Proceedings, vol. 23, pp. 149–154, 2025. [Online]. Available: https://doi.org/10.36287/setsci.23.62.001.

[21] AFAD (Disaster and Emergency Management Authority), "Türkiye Bina Deprem Yönetmeliği (TBDY-2018)," T.C. İçişleri Bakanlığı Afet ve Acil Durum Yönetimi Başkanlığı, Ankara, 2018. [Online]. Available: https://www.resmigazete.gov.tr/eskiler/2018/03/20180318M1-2.htm.

[22] International Code Council, "2018 International Building Code (IBC)," 2018. [Online]. Available: https://codes.iccsafe.org/content/IBC2018/chapter-2-definitions.

[23] Rockpanel, "High-rise buildings and fire safety," 2023. [Online]. Available: https://www.rockpanel.co.uk/product-benefits/firesafety/high-rise-buildings.

[24] R. Gifford, "The consequences of living in high-rise buildings," *Architectural Science Review*, vol. 50, no. 1, pp.

2–17, 2007. [Online]. Available: https://doi.org/10.3763/asre.2007.5002.

[25] H. Lee, "Psychological characteristics of high-rise residents," *International Journal of Sustainable Building Technology and Urban Development*, vol. 5, no. 1, pp. 10–20, 2014. [Online]. Available: https://doi.org/10.1080/2093761X.2014.876905.

[26] L. Jing, "Environmental impact of two types of residential building," *Urban Environment & Urban Ecology*, 2003.

[27] W. Xu, C. Jimenez-Bescos, and J. K. Calautit, "Evaluating the impact of neighbouring structures on a high-rise residential block's performance," *Building Simulation Conference Proceedings*, 2021. [Online]. Available: https://doi.org/10.26868/25222708.2021.30210.

[28] R. Rambabu, "Base isolation and energy dissipating system in earthquake resistant building design," *CVR J. Sci. Technol.*, 2024. [Online]. Available: https://doi.org/10.32377/cvrjst2603.

[29] M. R. B. Karimi and M. C. Geneş, "Optimized values for lead core rubber bearings for minimum response quantities," in *Proc. 6th Int. Conf. Civil Eng., Archit. Urban Planning Elites*, 2023. [Online]. Available: https://doi.org/10.33422/6th.caueconf.2023.08.10.

[30] M. Noureldin and J. Kim, "Simplified life cycle cost estimation of low-rise steel buildings using fundamental period," *Sustainability*, vol. 15, no. 3, 2023. [Online]. Available: https://doi.org/10.3390/su15032706.

[31] N. Ding, T. Chen, Y. Zhu, and Y. Lu, "State-of-the-art high-rise building emergency evacuation behavior," *Physica A: Stat. Mech. Appl.*, vol. 561, 2021. [Online]. Available: https://doi.org/10.1016/j.physa.2020.125168.

[32] L. Ma, R. Azari, and M. Elnimeiri, "A building information modeling-based life cycle assessment of the embodied carbon and environmental impacts of high-rise building structures: A case study," *Sustainability*, 2024. [Online]. Available: https://doi.org/10.3390/su16020569.

[33] International Energy Agency (IEA), "High-rise refurbishment," IEA Reports, 2022. [Online]. Available: https://www.iea.org/reports/high-rise-refurbishment.

[34] M. Sarcheshmehpour and H. Estekanchi, "Life cycle cost optimization of earthquake-resistant steel framed tube tall buildings," *Structures*, vol. 30, pp. 585–601, 2021. [Online]. Available: https://doi.org/10.1016/j.istruc.2021.01.038.

[35] United Nations Environment Programme (UNEP), "2022 Global Status Report for Buildings and Construction," UNEP, 2022. [Online]. Available: https://www.unep.org/resources/publication/2022-global-status-report-buildings-and-construction.

[36] United States Geological Survey (USGS), "Urban seismic hazards," USGS, 2023. [Online]. Available: https://www.usgs.gov/programs/earthquake-hazards/science/urban-seismic-hazards.

[37] The Global Footprint Network, "Ecological footprint of urban buildings," Global Footprint Network, 2022. [Online]. Available: https://www.footprintnetwork.org.

[38] A. K. Chopra, *Dynamics of Structures: Theory and Applications to Earthquake Engineering*. Englewood Cliffs, NJ, USA: Prentice Hall, 2012.

[39] *Eurocode 8: Design of Structures for Earthquake Resistance—Part 1: General Rules, Seismic Actions, and Rules for Buildings,* European Committee for Standardization, 2004.

[40] E. Budak, H. Sucuoglu, and O. Celik, "Response parameters that control the service, safety, and collapse performances of a 253 m tall concrete core wall building in Istanbul," *Bull. Earthq. Eng.*, vol. 21, no. 1, 2022. [Online]. Available: https://doi.org/10.1007/s10518-022-01527-4.

[41] F. Shadram and J. Mukkavaara, "Improving life cycle sustainability and profitability of buildings through optimization: A case study," *Buildings*, vol. 12, no. 4, 2022. [Online]. Available: https://doi.org/10.3390/buildings12040497.

[42] B. R. Viswalekshmi and D. Bendi, "A comprehensive model for quantifying construction waste in high-rise buildings in India," *Waste Manage. Res.*, 2023. [Online]. Available: https://doi.org/10.1177/0734242X231178227.

[43] UN-Habitat, *Enhancing Urban Safety and Security: Global Report on Human Settlements 2007*. UN-Habitat, 2007. [Online]. Available: https://unhabitat.org/sites/default/files/2020/09/grhs.2007.6.pdf.

[44] P. T. Thoi, T. H. Nguyen, and E. Harms, "Spaces of social capital across pandemic time: COVID-19 responses in Ho Chi Minh City's high-rise and low-rise neighborhoods," *City & Community*, 2023. [Online]. Available: https://doi.org/10.1177/15356841231198458.

[45] W. Dawood, M. Nazim, O. El-Mahdy, and M. Adam, "Soil-structure interaction assessment for seismic performance of high-rise RC building on piled-raft foundation," *Eng. Res. J. (Shoubra)*, 2024. [Online]. Available: https://doi.org/10.21608/erjsh.2024.263591.1274.

[46] K. Lai, C. Sarkar, S. Kumari, M. Y. Ni, J. D. Gallacher, and C. Webster, "Calculating a national anomie density ratio: Measuring the patterns of loneliness and social isolation across the UK's residential density gradient using results from the UK Biobank study," *Landsc. Urban Plan.*, vol. 215, 2021. [Online]. Available: https://doi.org/10.1016/j.landurbplan.2021.104194.

[47] World Green Building Council (WorldGBC), "Advancing net zero status report 2021," WorldGBC, 2021. [Online]. Available: https://worldgbc.org/article/worldgbc-details-built-environment-progress-to-achieving-net-zero-in-latest-report/.