

Research Article

Exploring a New Building Typology: Structural Hybrids

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Abstract In recent years, the increasing demand for iconic towers, coupled with intense competition among major cities to construct the most distinguished vertical structures and the continuous pursuit of building the world's loftiest structures, has come to characterize the forefront of modern high-rise architecture. In this race, many vertical structures have essentially become vertical extensions of land, primarily aimed at maximizing the financial value of the ground they occupy. However, this approach has often resulted in the proliferation of uninspiring and homogeneous towers across the globe, largely products of isolated architectural practices. Despite nearly 150 years of innovation, the architectural design of high-rise buildings has yet to fully achieve the desired advancement, particularly in terms of urban integration and structural design. In this study, the authors propose a classification system for contemporary high-rise typologies, with a particular focus on hybrid structures. The study underscores the importance of spatial quality and the integration of structural design, aiming to raise architects' awareness of structure as a fundamental element of architecture. Structural hybrids offer a transformative approach to high-rise design by integrating structure and architecture to overcome the limitations of standardized designs, creating dynamic and contextually enriched spaces.

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1. Introduction

High-rise buildings, much like the monumental Greek temples and Gothic cathedrals of earlier eras, have emerged as defining symbols of industrialized societies, embodying the technological and economic aspirations of modern cities (Gelernter, 2001). In the early 20th century, skyscrapers were primarily designed for office use, becoming key markers of American urban architectural development (Landau & Condit, 1999). These structures arose as a direct response to rapid urbanization, offering a vertical solution to the increasing demand for office space in densely populated areas. By concentrating work environments in high-rise buildings, cities could optimize land use and accommodate growing commercial activities. However, as the century progressed, the typology of high-rise buildings evolved significantly. The singular function of early office towers gave way to multifunctional buildings by the 1960s, reflecting broader social and economic transformations (Grubbauer, 2014). This shift toward multifunctionality aligned with the architectural concept of hybridization, which integrated diverse functions -such as residential, commercial, and leisure space- into a single vertical structure (Moussavi, 2007). This approach not only addressed the changing needs of urban populations but also optimized space utilization and efficiency in increasingly dense metropolitan environments. The transition from mono-functional towers to hybrid buildings demonstrated a growing awareness of the need for flexibility in architectural design, responding to the dynamic socio-economic forces that continue to shape urban landscapes. Today, high-rise buildings serve as multifunctional hubs, blending living, working, and recreational spaces, thus redefining their role in the fabric of modern cities and addressing the complex demands of contemporary urbanization (Ogura, Yap, & Tanoue, 2002).

Before the emergence of rigid frame systems, architectural practices were dominated by masonry construction, which relied on load-bearing masonry walls for structural stability (Han et al., 1997). While these walls provided excellent fire resistance, their substantial dead loads and thick cross-sections significantly limited usable interior space, posing a challenge for efficient building design (Ali & Moon, 2007). A transformative shift occurred in the late 19th century with the invention of the elevator and the development of the beam-column framing system, which introduced structural steel as a core component of skyscraper construction. This innovation, alongside advancements in materials, structural engineering, and mechanical systems, marked a turning point in the design of high-rise buildings (Taranath, 2016). The integration of steel framing not only allowed for greater height and slimmer building profiles but also facilitated more open and flexible floor plans, making high-rise buildings more functional and space-efficient. These technological breakthroughs revolutionized the construction industry in the United States, accelerating the rise of vertical structures and sparking a global race for verticality (Kontokosta, 2013). As cities around the world began competing to construct taller and more iconic structures, vertical structures became emblematic of modern urban development, symbolizing progress, innovation, and economic power. This period of rapid evolution laid the groundwork for the skyscraper's prominent role in shaping the skylines of major cities, establishing high-rise buildings as enduring symbols of architectural and technological achievement (Barr & Jedwab, 2023).

A high-rise building is typically structured into three primary sections: the crown (top), shaft (main body), and podium (base). This tripartite design strategy, which emerged in the late 19th century, became a hallmark of skyscraper architecture and is exemplified by iconic structures like the Chrysler Building in New York (1930). The division into these distinct components serves both functional and aesthetic purposes, contributing to the architectural coherence of high-rise buildings (Al-Kodmany & Ali, 2016). The podium anchors the building at street level, creating a vital interface with its urban surroundings and often housing commercial or public spaces that engage with pedestrian activity. The shaft, or main body, is the building's core, responsible for managing the structural and environmental demands placed on high-rise buildings, such as wind loads and solar exposure. While crucial in shaping how the building interacts with its environment and perceived height, the shaft often becomes a repetitive sequence of stacked floors driven by economic motives, focused on maximizing leasable or functional space (Ali & Armstrong, 1995). Lastly, the crown, which typically houses mechanical systems or serves as an aesthetic feature, plays a significant role in defining the building's skyline and iconic status.

Contemporary high-rise buildings, driven by cutting-edge structural analysis and sophisticated computer technologies, exhibit innovative architectural and structural solutions that were previously unattainable in earlier design paradigms (Alkhatib et al., 2024; Rane et al., 2024; Yan et al, 2024). These advances have enabled the creation of vertical structures with complex geometries, unprecedented heights, and enhanced performance in terms of load-bearing capacity, seismic resilience, and energy efficiency. However, despite these technological breakthroughs, many modern high-rises have developed into self-contained, inward-focused structures, often lacking meaningful engagement with their urban context and cultural surroundings (Harris & Wolseley, 2024). This trend reflects a shift toward self-referential design, where aesthetic and engineering achievements are prioritized over social or cultural integration. As a result, these buildings frequently appear isolated from the social fabric of the city, contributing little to the public realm or community interaction (Koolhaas, 2008; Scheeren, 2014; Henn & Fleischmann, 2015; Safarik, 2016). While these vertical structures stand as monuments to technological prowess and architectural ambition, their disconnection from the broader urban environment raises concerns about the role of architecture in fostering social cohesion and enhancing the quality of life in cities. The challenge for future skyscraper design lies in balancing the technological innovations that define modern high-rise construction with a renewed focus on creating buildings that are not only visually striking but also culturally and socially integrated into their urban surroundings.

In recent years, the increasing emphasis on aesthetics and stylistic innovation in skyscraper design has, in some cases, overshadowed the importance of structural integrity (Ubayi et al., 2024). This focus on form over function can result in the repetitive use of structural systems across floors, limiting the ability of structural design to address unique architectural challenges and to engage dynamically with the overall design of the building (Elnimeiri & Almusharaf, 2010). As a consequence, there has been a trend toward rigid homogeneity in the structural layouts of modern vertical structures, where the structural system remains uniform throughout the building's height, often at the expense of functional adaptability and the specific requirements of the occupants. This repetitive approach compromises the integration of

structural systems into the building's broader architectural vision, reducing the potential for innovation in both form and function. While such designs may ensure that the building remains structurally sound, they often miss opportunities to enhance spatial quality, flexibility, and user experience by failing to adapt the structure to different programmatic needs or to engage with the building's aesthetic in a meaningful way. A more integrated approach, where structural design actively contributes to the architectural expression and functionality of the skyscraper, is crucial for advancing the design of high-rise buildings, ensuring that they meet both engineering and architectural objectives.

This study focuses on the critical role that structural systems play in shaping and organizing architectural space, emphasizing how structure can actively contribute to the architectural narrative -at times subtly "speaking" or more boldly "shouting" depending on its design and integration within the built environment. In addition to investigating the expressive capacity of structural design, the study explores the concept of spatial hybrids, which combine different spatial typologies to enhance both spatial quality and sustainability. These hybrids integrate various functions within a cohesive design framework, creating dynamic spaces that respond to the diverse needs of occupants while promoting efficient use of resources. The research further explores functional hybrids -buildings that combine multiple uses- illustrating how such designs can achieve a higher degree of adaptability and resilience in the face of changing urban demands. Through a detailed analysis of representative case studies, this paper demonstrates how high-rise buildings, when designed with a thoughtful integration of structure and function, have the potential to humanize urban environments, contributing positively to the social and ecological fabric of cities. Table 1 illustrates how innovative structural systems tackle evolving challenges while enhancing architectural expression and urban livability.

Table 1. Innovative approaches and the role of structural systems in contemporary high-rise building design (prepared by the authors).

Aspect	Description
Challenges	Addressing the evolving needs of urban environments by rethinking traditional typologies.
Role of Structural Systems	Structural systems should transcend their primary load-bearing function and become active architectural elements shaping the overall design.
Design Benefits	<ul style="list-style-type: none"> - Regulates the organization of floor plans. - Establishes clear spatial hierarchies enhancing functionality and aesthetics. - Adds visual diversity and complexity. - Optimizes building performance.
Dynamic and Adaptable Spaces	Strategic integration of structural systems enables dynamic spaces responsive to user needs and urban context.
Innovative Approach	Moves away from rigid, uniform layouts, fostering more flexible, innovative, and visually engaging designs.

Architects designing contemporary high-rise buildings must address the evolving challenges of urban environments by rethinking traditional typologies and exploring innovative approaches in which structural systems play a more active architectural role beyond their primary function of load-bearing.

It is worth noting that according to the criteria established by the Council on Tall Buildings and Urban Habitat (CTBUH, 2024), a ‘tall building’, namely high-rise in this study, is defined as a structure with a minimum height of 14 stories or 50 meters, extending up to 300 meters.

2. Hybrids

Hybrids have emerged as a prominent architectural model within contemporary high-rise building typology, representing a significant shift in how we conceive of function, spatial organization, and structural design. Despite their growing recognition, the full potential of hybrid buildings -those that integrate multiple functions and spatial configurations within a single structure- remains underexplored. These buildings offer a promising alternative to traditional mono-functional high-rises, presenting opportunities for greater flexibility, efficiency, and adaptability to the complexities of modern urban life. In this paper, the authors build upon a range of foundational studies (e.g., Rowley, 1996; Salingaros, 1998; Talen & Knap, 2003; Per et al., 2014; Ravindranath & Menon, 2018; Bagley, 2018) to propose a refined classification for hybrid high-rise buildings. This classification aims to clarify the typological distinctions and design principles that characterize hybrids, encompassing both functional integration and innovative structural solutions. By establishing a more detailed framework, the study seeks to advance our understanding of hybrid high-rise buildings, positioning them as a critical response to the demands of modern urbanization, environmental sustainability, and the need for spatial efficiency in increasingly dense cities.

- Functional hybrids
- Spatial hybrids
- Structural hybrids

Table 2 outlines hybrid classifications, emphasizing their key features and advantages in contemporary high-rise building design.

Table 2. A new approach to hybrid structures in high-rise building typology (prepared by the authors.)

Category	Definition	Features and Advantages
Functional Hybrids	Integration of multiple functions (e.g., office, residential, commercial spaces) within a single structure.	- Flexibility - Adjusting to the challenges of contemporary urban life - Alternative to single-function buildings
Spatial Hybrids	Integration of diverse spatial organizations or functions within a building.	- Innovative use of space - Efficiency in dense urban areas - Inclusive design
Structural Hybrids	Combining structural systems innovatively to create efficient, sustainable solutions that accommodate complex functions.	- Environmental sustainability - Flexibility to accommodate high-density requirements - Resourceful response to modern urbanization

2.1. Functional hybrids

Extensive research in the literature (e.g., Salingaros, 1998; Holl, 2011; Per et al., 2014; Ravindranath and Menon, 2018) reveals a clear evolutionary trajectory in high-rise building typology, transitioning from the single-use mega towers that characterized early modernism to the complex multifunctional hybrids that dominate contemporary urban landscapes. The shift from mono-functional towers, primarily focused on office or commercial use, reflects the

broader social and economic transformations of the 20th and 21st centuries. Early modernist vertical structures, rooted in industrialization and economic growth, were designed to maximize vertical efficiency for singular purposes, often neglecting the social and spatial complexities of rapidly urbanizing environments (Aragão, 2024). As cities grew more intricate and the needs of their inhabitants became increasingly diverse, the architectural paradigm began to shift. Today's multifunctional hybrids integrate residential, commercial, and recreational spaces within a single structure, creating adaptable environments that better align with the demands of modern urban life (Kausaret al., 2024). Table 3 outlines the evolution, key features, and importance of functional hybrids, highlighting their role in meeting modern urbanization challenges.

Table 3. Functional hybrids in high-rise building typology (prepared by the authors).

Aspect	Description
Evolution	Transition from single-use towers (e.g., office-focused) of early modernism to multifunctional hybrids integrating residential, commercial, and recreational spaces.
Drivers	<ul style="list-style-type: none"> - Social and economic shifts - Urbanization complexities - Need for flexible, integrated environments
Key Features	<ul style="list-style-type: none"> - Adaptability - Mixed-use integration - Elevated living conditions and sustainability
Examples	Marina City Complex (Chicago, 1964): A pioneering 'city-within-a-city' concept blending residential, commercial, and recreational uses.
Primary Functions	Office, residential, hotel
Secondary Functions	Retail spaces, parking, observatories
Design Challenges	<ul style="list-style-type: none"> - Complex programmatic zoning - Efficient circulation systems - Balancing privacy with public amenities
Significance	Functional hybrids align with modern urban needs, combining diverse functions to foster economic viability and improve spatial efficiency.

These hybrids are not just a response to the need for space efficiency; they embody a more nuanced understanding of urban ecosystems, blending diverse functions in a way that enhances livability, economic viability, and environmental sustainability (Vreeker et al, 2004).

The evolution toward multifunctional vertical structures also reflects a deeper integration of architectural form and urban planning, where buildings are designed to serve as dynamic hubs within their urban context, fostering interaction and adaptability in response to ongoing social and economic shifts. This progression underscores the critical role of high-rise buildings in shaping not only the skyline but also the functional and social fabric of contemporary cities.

In the design of high-rise buildings, function plays a pivotal role, shaping nearly every other aspect of architectural and structural decision-making (Scaramozzino et al., 2022). The functional requirements of a building -whether it is intended for residential, commercial, or mixed-use purposes- serve as the foundational framework around which the entire design is developed. These functional needs dictate not only the spatial configuration and vertical zoning but also influence the selection of structural systems, materiality, and mechanical integration. For instance, a high-rise designed primarily for office use will have different floor plate dimensions, core layouts, and circulation requirements compared to a residential or mixed-use tower, where flexibility and adaptability are more critical (Rabianski et al., 2009).

Furthermore, the functional role of a building affects its interaction with urban context, particularly in how it contributes to or supports surrounding infrastructure and community needs. As such, function is not merely a consideration but a dominant factor that must be integrated at the earliest stages of the design process, guiding the architectural vision and ensuring that the building meets its intended purpose efficiently and sustainably. Ignoring functional imperatives in the early phases can lead to design inefficiencies, compromised performance, or a failure to address user needs, ultimately impacting the building's long-term success within its urban environment. Thus, architects and engineers must prioritize a building's function from the outset, using it as a critical lens through which other design elements are conceptualized and optimized.

The functional classification of high-rise buildings can generally be categorized into two primary types: single-use and multifunctional (mixed-use) structures (Chau, et al., 2007).

Single-use buildings are designed to accommodate a single function, such as office, residential, or commercial space, while multifunctional towers integrate a variety of functions within a single structure, creating a dynamic mix of uses. The emergence of multifunctional high-rise buildings in the mid-1960s marked a significant shift in urban design, addressing the need for more flexible, integrated environments within rapidly growing cities. As seen in Figure 1, a pioneering example of this typology is the Marina City Complex in Chicago (1964), designed by Bertrand Goldberg & Associates. Standing at 61 stories and 179 meters in height, Marina City was one of the first developments to embody the 'city-within-a-city' concept, blending residential, commercial, and recreational spaces into a single cohesive structure (Kim, 2004). The complex's innovative design featured a reinforced concrete construction with a shear-walled frame system, enabling it to efficiently accommodate the diverse functional demands of its occupants while ensuring structural stability. This multifunctional approach not only optimized land use but also fostered a more integrated urban experience, allowing residents to live, work, and socialize within the same vertical environment. The success of Marina City paved the way for the widespread adoption of mixed-use towers, which have become a fundamental component of modern urban development strategies.

Today, these multifunctional high-rises are seen as essential solutions for addressing the complexities of urbanization, promoting sustainability, and enhancing the quality of life in dense metropolitan areas.

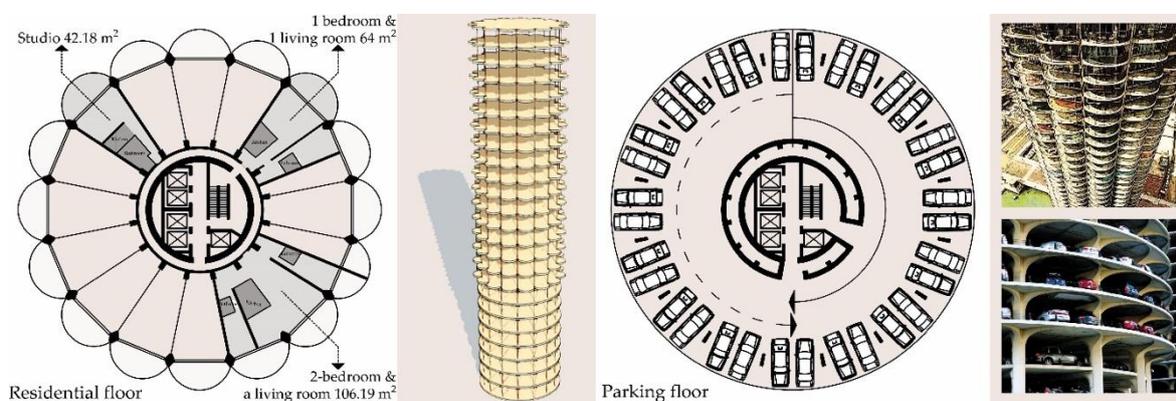


Figure 1. Marina city complex (prepared by the authors).

Goldberg's Marina City Complex, completed in 1964, was a landmark in urban development as the first planned multi-use project in Chicago and, at the time, the tallest residential building in the world. With its distinctive corn-cob-shaped towers, the Marina City Complex became an iconic example of mid-20th-century architectural innovation. The project departed from traditional single-function high-rises by integrating residential, commercial, and recreational facilities within a single development; encapsulating the 'city-within-a-city' concept. Each residential floor was designed with unique layouts, ensuring no two floors were identical, which contributed to the building's architectural distinction. This individualized floor design emphasized residential diversity, making it stand out from previous large-scale developments that often featured repetitive layouts. However, while Marina City excelled in its integration of multiple functions, it fell short in the creation of public spaces that could foster community interaction and shared experiences within its interior. Unlike more contemporary spatial hybrid models, which emphasize the importance of common areas and public spaces for enhancing social interaction, Marina City's design focused primarily on the functional separation of its different uses. This limited the project's potential for spatial articulation, reducing opportunities for dynamic interactions between residents and between different building functions. Despite this, Marina City remains a pioneering example of multifunctional high-rise design and continues to influence modern urban planning and mixed-use development strategies.

In the design of high-rise buildings, the primary functions typically encompass office, hotel, and residential uses, which form the core purposes of the structure. Secondary functions, such as commercial/retail spaces, parking facilities, and observatories, serve as supportive or ancillary elements that complement the building's primary uses. Multifunctional high-rise buildings are often classified based on the complexity of their programmatic combinations, which can include office and hotel, office and residential, or a more integrated mix of office, hotel, and residential functions within a single tower (Kim & Elneimeiri, 2004). These multi-use configurations present unique challenges in terms of architectural design and structural engineering, as they require sophisticated building cores and circulation systems capable of managing the diverse needs of different occupants (Park, 2005). For example, office spaces typically demand efficient vertical circulation through high-speed elevators and large floor plates, while residential areas may require more private, segmented cores with distinct service areas. Hotels, on the other hand, often necessitate both private and public zones with specialized amenities. Integrating these diverse functional requirements into a single high-rise structure involves a complex interplay of zoning, structural support, and circulation strategies, ensuring that each function operates efficiently while maintaining overall structural coherence. This complexity underscores the importance of innovative core design and flexible circulation systems in the successful execution of multifunctional vertical structures, which must seamlessly accommodate the varied needs of commercial, residential, and hospitality sectors within the confines of a single vertical form.

In contemporary high-rise building typology, functional hybrids have become a defining characteristic, reflecting the growing demand for flexible, adaptive spaces that serve multiple purposes. These hybrid structures can be designed for either single-use, where different functions are separated vertically or horizontally within the building, or for multifunctional use, where various functions coexist and interact more dynamically. While functional hybrids offer

considerable advantages in terms of versatility and space optimization, they often face challenges related to spatial quality and architectural diversity. Minor volumetric adjustments, such as the stacking of distinct functions or the inclusion of various programmatic elements, are frequently employed to accommodate different uses within the same structure. However, this approach can sometimes overlook the broader considerations of spatial experience, leading to homogeneous environments that lack the richness and complexity found in more architecturally diverse designs. The integration of multiple functions in a single high-rise demands careful attention to how space is articulated and how different functions interact, both visually and operationally, within the building. Without this focus, hybrid buildings risk becoming functionally efficient but spatially monotonous, failing to fully leverage the potential for architectural innovation that comes with combining diverse uses. Achieving a balance between functionality and spatial quality is, therefore, critical in the ongoing development of hybrid high-rise buildings, as it ensures that these structures not only meet the practical demands of urban life but also contribute meaningfully to the aesthetic and experiential fabric of the cities they inhabit.

In the pursuit of improving spatial quality in high-rise building design, the concept of spatial hybrids has emerged as a pivotal advancement in the evolution of skyscraper typology. Spatial hybrids integrate diverse functions and spatial arrangements within a single structure, offering a more nuanced and dynamic approach to space utilization compared to traditional mono-functional high-rises. These hybrids go beyond simple functional zoning by creating a richer, more interconnected spatial experience that enhances both the usability and aesthetic appeal of the building. By layering various programmatic elements -such as residential, commercial, recreational, and public spaces- spatial hybrids foster greater flexibility and adaptability, allowing buildings to respond more effectively to the diverse and evolving needs of urban populations. This approach not only optimizes the internal flow and interaction between different functions but also promotes a sense of spatial diversity and complexity that enriches the overall architectural experience. Furthermore, spatial hybrids often emphasize the creation of shared or communal areas, which can serve as hubs for social interaction and engagement, contributing to the building's role as a social and cultural catalyst within the urban environment. As the demand for multifunctional and adaptable urban spaces continues to grow, spatial hybrids represent a forward-looking strategy in high-rise building design, blending functionality with spatial innovation to create buildings that are both efficient and experientially rich. The following section will delve deeper into the specific typologies and design principles that characterize this emerging trend in architectural practice.

2.2. Spatial hybrids

Spatial hybrids refer to high-rise buildings designed with either single-use or multifunctional purposes, offering a significant alternative to the conventional vertical stacking of repetitive functional units. Unlike traditional high-rises that have relied on uniform or similar floor plans throughout, spatial hybrids are conceived to foster architectural diversity by responding to the varied needs of users across different levels. This approach moves beyond the typical repetition of floor layouts, embracing a more dynamic spatial organization that incorporates a variety of functions, configurations, and experiences within the vertical form of the building.

During the design process, multiple criteria are considered to enhance the functionality and liveability of these hybrids. Key design elements might include the integration of transportation systems with multi-level access points, the incorporation of shared green spaces and social areas at different heights, and the seamless blending of cultural, environmental, and social considerations (Koolhaas, 2008; Per et al., 2014; Scheeren, 2014; Safarik, 2016; Ravindranath and Menon, 2018). These factors contribute to the overall urban impact of the building, allowing it to serve as a more integrated component of the city's fabric. According to Holl (2011), "Spatial hybrids are high-rise buildings with a mixed-use gene in their DNA, revitalizing the urban scene and conserving valuable space". This innovative typology enhances the flexibility and adaptability of high-rise buildings, making them more responsive to contemporary urban challenges such as sustainability, density, and social interaction. By creating spaces that are diverse, interconnected, and multifunctional, spatial hybrids represent a forward-thinking approach to high-rise design, contributing not only to architectural innovation but also to the enrichment of the urban experience.

As profit-driven developments, high-rise buildings frequently offer limited green and social spaces for their occupants, both at ground level and at elevated heights (Koolhaas, 2008; Scheeren, 2014). This scarcity of shared public facilities contributes to a sense of detachment from the human scale, particularly in high-rise environments where vertical stratification often reduces opportunities for social interaction and communal engagement. To address this challenge and reintroduce a more human-centric approach to high-rise building design, spatial hybrids can incorporate a range of architectural features aimed at creating communal spaces and enhancing the user experience. Strategies such as sky gardens, sky bridges, and sky decks serve as elevated extensions of the public realm, effectively creating "streets in the sky" that foster social interaction, provide access to green spaces, and mitigate the isolating effects of vertical living (Wood, 2003; Robinson & Wood, 2014). These features not only enhance the liveability of high-rise buildings by bringing nature and community spaces into the vertical environment but also contribute to the overall well-being of occupants by providing opportunities for recreation, relaxation, and social connection. By integrating these elements, spatial hybrids can balance the profit-oriented nature of high-rise developments with the need for meaningful communal spaces, ultimately producing buildings that are not only economically viable but also socially and environmentally responsive. This approach reflects a broader trend in contemporary architecture toward the creation of multifunctional, adaptable spaces that prioritize human experience while addressing the challenges of urban density and sustainability.

The Interlace in Singapore (2013) and MahaNakhon in Bangkok (2016) stand as exemplary instances of spatial hybrids, showcasing innovative approaches to integrating diverse functions within a single architectural form. These projects are renowned for their bold architectural expression and ability to create dynamic, multifunctional environments that challenge traditional high-rise typologies. However, even within these landmark examples, there are notable instances where the structural systems appear to conflict with or constrain functional objectives. In both cases, the load-bearing vertical elements—essential for ensuring structural stability—introduce spatial constraints that can frustrate users, particularly in areas where the structure disrupts circulation, visual continuity, or flexibility of use. This tension arises because

the primary design emphasis was placed on achieving other architectural goals, such as form, aesthetics, or urban impact, rather than fostering a deeper synergy between structural performance and spatial functionality. The prioritization of these aesthetic or conceptual objectives sometimes comes at the expense of optimizing the relationship between structure and function, leading to challenges in user experience and space utilization. This reflects a broader issue in the design of high-rise buildings, where the complexity of integrating architectural and structural systems often results in compromises that can affect the functionality of the built environment. To fully realize the potential of spatial hybrids, future projects must place greater emphasis on the interplay between structure and architecture, ensuring that structural elements not only fulfil their load-bearing roles but also contribute positively to the spatial and functional coherence of the design. This balance is crucial for advancing high-rise building typology and achieving more harmonious and user-friendly high-rise environments.

2.2.1. Analysis of the Interlace

The Interlace, a 24-storey, 89-meter high residential complex in Singapore, was designed by the Office for Metropolitan Architecture (OMA) in collaboration with Ole Scheeren. This project, constructed with a reinforced concrete frame and shear wall system, has garnered significant acclaim, winning the prestigious 'Urban Habitat Award' and being recognized as a finalist for 'Best Tall Building Asia & Australasia' in the 2014 Council on Tall Buildings and Urban Habitat (CTBUH) Awards Program.

Although The Interlace does not strictly meet CTBUH's definition of a high-rise building, it was included in its awards program due to its innovative spatial and structural typology, which aligns with the broader objectives of CTBUH to promote advancements in urban habitat and tall building design. The project demonstrates how alternative approaches to building design can address the evolving challenges of urban living and redefine the concept of "height" in architectural terms. This inclusion reflects the organization's willingness to expand its evaluation criteria beyond conventional height metrics to embrace projects that innovate in form, function, and context.

As one of Singapore's largest residential developments, spanning 170,000 square meters of built floor area, The Interlace is often referred to as a "vertical village", as seen in Figure 2. The complex features 1,040 apartment units distributed across 31 six-storey blocks, each 70 meters long, arranged in a striking hexagonal configuration around eight expansive, permeable courtyards. These courtyards and multi-storey openings create a porous massing that allows for natural light and ventilation to flow freely through the building.

The Interlace was chosen for this study due to several compelling reasons, as summarized in Table 4 are presented below:

Table 4. Justifications for including the interlace in the study (prepared by the authors).

Rationale	Explanation
Focus on Spatial Hybrids	The project exemplifies innovative spatial solutions, which are central to the study's exploration of structural hybrids.
Shift from Vertical to Horizontal Integration	Its horizontal arrangement challenges traditional vertical stacking models, providing a new typology for high-rise buildings.
Reinterpretation of Height	While not physically high-rise, the project redefines "height" by layering space horizontally in a dynamic configuration.
CTBUH Recognition	Despite its unconventional form, CTBUH acknowledged the project for its innovative contributions to high-rise building design.
Integration of Structure and Architecture	The Interlace highlights the interplay between structural elements and spatial organization, a core focus of the study.
Social and Ecological Contributions	The design fosters community interaction and integrates with nature, aligning with the goals of spatial hybrids.

Beyond its innovative structural and spatial arrangement, The Interlace distinguishes itself by creating a balance between public and private spaces. The development fosters social interaction through its extensive public amenities, which include leisure and recreational facilities, as well as outdoor spaces designed to accommodate a variety of activities. The integration of these public spaces not only supports communal living but also contributes to the project's goal of embedding the architecture within its natural surroundings through a thoughtful landscaping strategy. This design approach generates a harmonious relationship between the built environment and nature, reinforcing the project's status as a prototype for spatial hybrids.

The Interlace challenges the conventional model of vertical high-rise living by introducing a horizontally layered, interlocking configuration of apartment blocks. This spatial formation, in contrast to the monotonous vertical stacking typical of residential towers, enhances the quality of life by generating ample public spaces and recreational areas within the complex. The horizontal orientation of the hexagonal blocks produces a series of interconnected communal spaces, effectively turning vertical isolation into horizontal integration. This innovative design fosters a village-like atmosphere, where the complex interplay between private and public spaces, as well as their relationship with the surrounding natural environment, is thoughtfully articulated to create distinct spatial identities. The Interlace represents a ground-breaking approach to residential design, offering a model for future developments seeking to integrate architecture, community, and nature in a cohesive and sustainable manner (Scheeren, 2014; Safarik, 2016; Ravindranath and Menon, 2018).

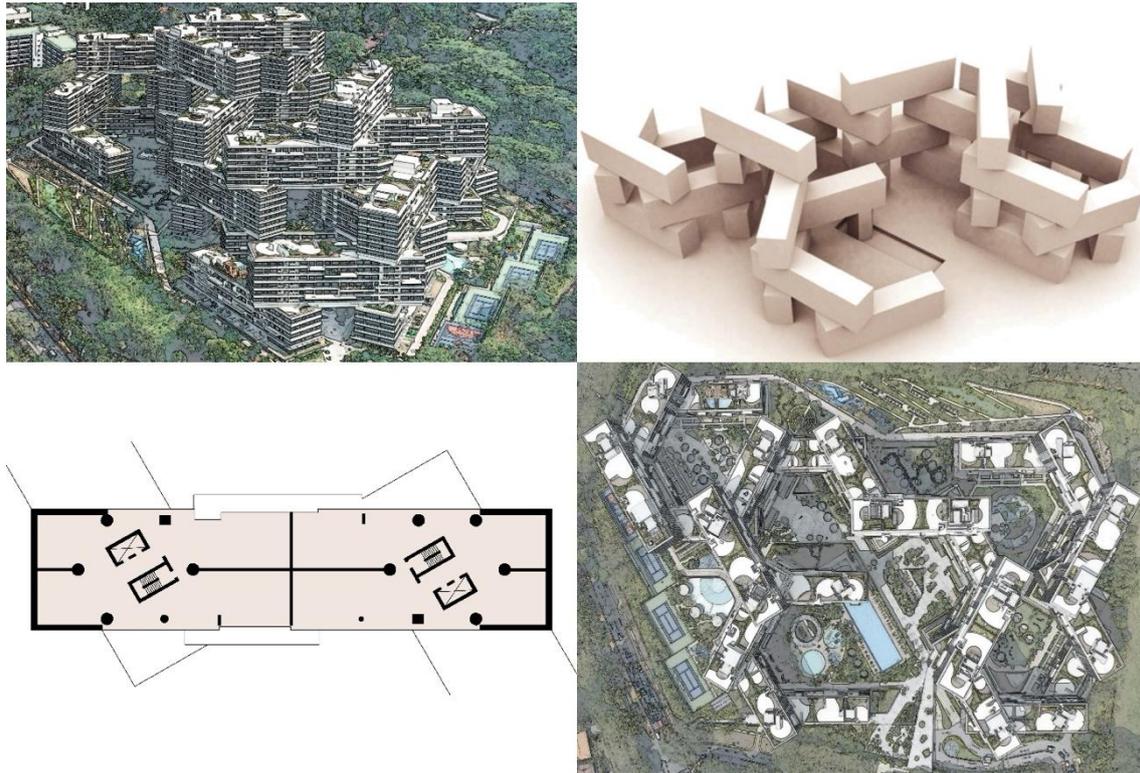


Figure 2. The interlace (prepared by the authors).

The Interlace, with its numerous positive design features, serves as a remarkable example of spatial hybrids, demonstrating innovative approaches to community-building and space organization. However, the interior planning of the complex has been compromised by structural disruptions, which limit the flexibility and functionality of interior spaces. As illustrated in the typical floor plan (Figure 2), the arrangement of key structural elements, such as shear walls and mega columns, lacks full integration with the architectural layout, leading to spatial inefficiencies. This misalignment between structure and function restricts the adaptability of interior spaces, imposing constraints that undermine the building's potential for long-term versatility.

In particular, the placement and size of the mega columns are problematic, not only because they physically dominate interior spaces but also because they negatively affect the fluidity of movement between different areas. The oversized structural elements, while necessary for load-bearing purposes, tend to overwhelm the occupants and impede the natural flow of space. Additionally, the repetition of the same structural configuration across multiple floors further exacerbates these issues, creating a rigidity in spatial use that is less responsive to the evolving needs of residents over time. This approach limits the potential for dynamic reconfiguration of the spaces, particularly as future user needs may shift.

Despite the success of The Interlace as an alternative to the conventional vertical stacking of residential units, and its innovative role as a spatial hybrid, the project falls short in its integration of structural design as a core architectural parameter. The emphasis on other architectural objectives -such as the overall form and external massing- has led to a structural design that interrupts function, rather than supporting or enhancing it. For example, while the complex's hexagonal arrangement of blocks and open courtyards creates visually and

experientially engaging communal spaces, the interior environments suffer from a lack of coherence between structural and spatial design. In conclusion, while The Interlace offers an alternative spatial typology that challenges traditional high-rise models, its limited attention to structural-architectural integration reveals an area for improvement in the evolution of future spatial hybrids.

2.2.2. Analysis of MahaNakhon

The MahaNakhon, a striking 75-storey, 314-meter tall tower in Bangkok (Figure 3), was designed by the Office for Metropolitan Architecture (OMA) in collaboration with Ole Scheeren. As a reinforced concrete multifunctional skyscraper, it employs an outriggered frame system to provide the necessary structural support for its towering height. The name 'MahaNakhon,' meaning 'great metropolis' in Thai, reflects the building's ambitious scale and its role as a landmark in Bangkok's urban landscape. One of the most distinctive aspects of MahaNakhon's design is its pixelated form, a deconstructed architectural expression that has gained global recognition for its innovative approach to resolving the challenge of vertical height. This pixelation not only enhances the building's overall height but also creates unique residential layouts, where each floor features different configurations, breaking away from the repetitive floor plans typically seen in high-rise buildings (Chanvaivit et al., 2015).

The pixelated design also establishes a stronger connection between the building and the street, dissolving the traditional boundary between the tower and its urban surroundings. As the tower descends toward the ground, its form becomes more dynamic, modulating into a multi-level topography of cascading indoor and outdoor spaces. This approach departs from the conventional use of a podium and instead creates a series of terraced occupiable volumes, fostering a seamless integration with the surrounding cityscape. These terraces not only enhance the building's aesthetic appeal but also provide a mix of indoor and outdoor environments, further blurring the line between the built and natural worlds. By incorporating organic forms and offering diverse spatial experiences, MahaNakhon's design creates a more human-centric connection to its surroundings, promoting greater engagement with the urban fabric while maintaining its iconic presence as one of the tallest buildings in Southeast Asia. The tower's innovative design, blending function, form, and context, positions it as a pioneering example of how vertical structures can redefine their interaction with the city and the people who inhabit them.

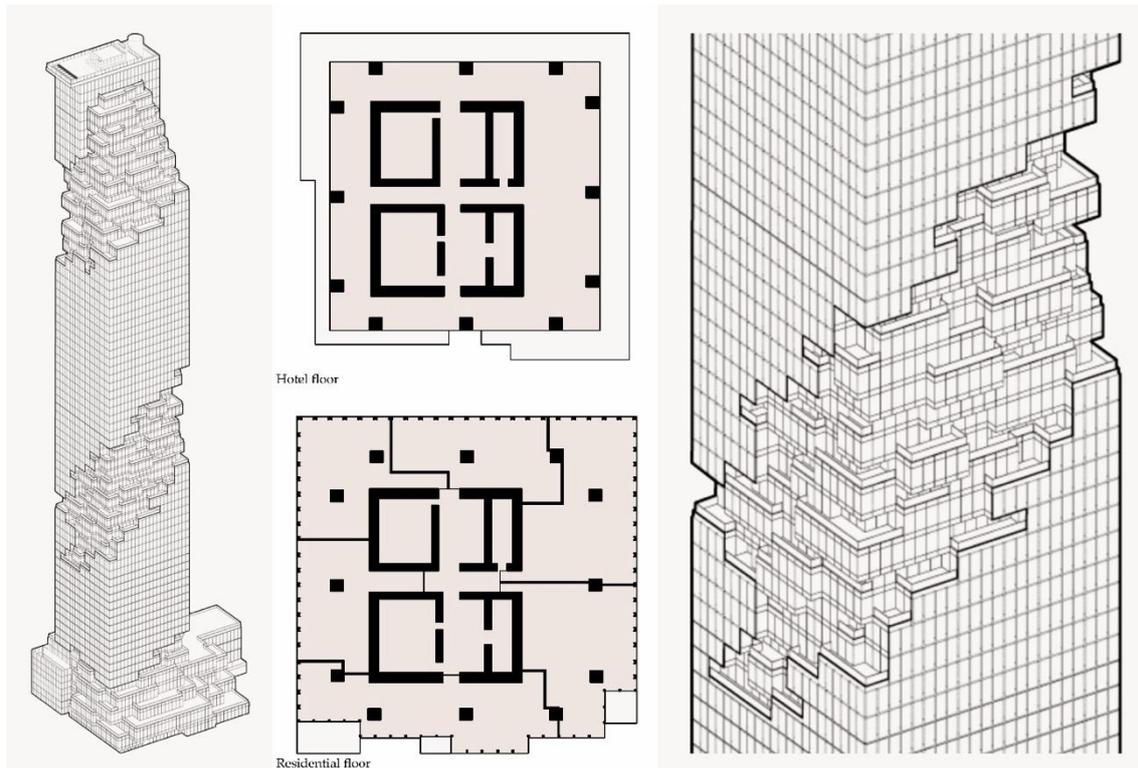


Figure 3. MahaNakhon (prepared by the authors).

Much like The Interlace, the MahaNakhon project seeks to establish an architectural prototype for spatial hybrids by departing from the conventional model of vertical stacking for multifunctional units. Through its carefully carved, three-dimensional pixelated form, the building introduces a dynamic alternative to repetitive high-rise layouts, engaging more actively with the surrounding urban context (Techakraisri, 2016). The mass-breaking form of MahaNakhon, characterized by its distinctive architectural “pixels” spiralling up the tower's full height, generates a diverse array of indoor and outdoor spaces, setbacks, balconies, and terraces. This design not only responds to user preferences by offering varied spatial experiences but also enhances the building's interaction with the city and its urban fabric, creating a more fluid and integrated relationship between the structure and its environment.

While the architectural form is innovative, the structural approach remains somewhat conventional, focused on maintaining an economically efficient and repetitive form wherever possible. In contrast to The Interlace, where large structural elements often dominate interior spaces, MahaNakhon's design aims to minimize the overwhelming presence of load-bearing components. However, the repetition of the same structural configuration across multiple floors still limits the building's ability to fully adapt to the diverse and evolving needs of its users over time. This uniformity in structural design constrains the flexibility and long-term functionality of the space, highlighting a disconnect between the innovative architectural form and the structural solutions employed.

These case studies - both The Interlace and MahaNakhon - reveal a broader challenge in high-rise building design: the lack of harmony between architecture and structure. This tension underscores the need for a more integrated design approach, leading to the emergence of structural hybrids as the next step in the evolution of high-rise building typology. In structural

hybrids, the structure itself is no longer a passive element that merely fulfils its load-bearing function; instead, it actively contributes to the architectural expression and functional richness of the design. The goal is for the structure to enliven and articulate interior spaces, enhancing both aesthetic quality and building performance.

In the case of MahaNakhon, while the pixelated form presents opportunities for spatial diversity and urban engagement, the conventional structural design falls short of fully exploiting these opportunities to enrich the architecture through “space-making”. The major design and engineering challenges posed by the tower's unique form and slender proportions are addressed primarily through traditional structural solutions that prioritize efficiency and repetition over architectural innovation. For high-rise buildings to evolve into true structural hybrids, there must be a more nuanced understanding of how structure can enhance and articulate space, contributing not only to the building's stability but also to its architectural identity and functionality. This integrated approach would allow future high-rise buildings to transcend their current limitations, offering greater flexibility, spatial richness, and aesthetic depth.

2.3. Structural hybrids

The potential for a building's structure to either enhance or disrupt functional flexibility depends heavily on the degree of its integration with the architectural design concept and the specific functional requirements of the building (Charleson, 2015). Schumacher (2014) asserts that “the adaptation of structural morphologies to the force distribution within a structural system offers a fantastic opportunity for architectural articulation”. He further explains that the more intricate architectural orders proposed in contemporary design can be accentuated and expressed by highly sophisticated, adaptive structures. Structure thus plays a fundamental role in building functionality, not only by providing the essential load-bearing capacity but also by defining space, modulating surfaces, and creating a sense of architectural excitement.

However, despite the potential for structure to contribute meaningfully to architectural quality, there is yet to be a high-rise building project that fully satisfies all these conditions. Even exemplary projects such as The Interlace and MahaNakhon, while addressing spatial quality to some extent, still lack complete integration between architectural planning and structural design flexibility. These limitations -particularly the disconnection between architectural and structural systems- underscore the need for structural hybrids. In such hybrids, structure transcends its primary load-bearing role to become an active contributor to aesthetic, spatial, and functional richness. Rather than merely supporting the building, the structure becomes an inseparable part of the architecture, defining its form, generating spatial complexity, and enhancing the overall design.

Structural hybrids are characterized by their ability to use structure as a spatial organizer, creating an adaptive architectural design that does not compromise spatial quality, unlike traditional high-rise buildings where repetitive structural configurations limit flexibility across floor plans. These hybrids represent a new typology where various functions are not simply stacked vertically with uniform structural systems; instead, the structure itself evolves in response to different functional, spatial, and aesthetic needs throughout the building. Realizing

this vision requires close collaboration between innovative architectural and structural designers, who must work together to explore new structural form-finding logics that can discipline spatial morphologies in ways beneficial for the articulation of architectural language. Table 5 outlines the defining characteristics, benefits, and examples of structural hybrids, emphasizing their potential to integrate architectural and structural design seamlessly.

Table 5. Key characteristics of structural hybrids (prepared by the authors).

Aspect	Description
Definition	High-rise buildings where structural systems go beyond their load-bearing role to contribute to spatial organization, architectural expression, and functionality.
Key Features	<ul style="list-style-type: none"> - Structure as a spatial organizer - Adaptive structural morphologies - Integration of architectural and structural design
Potential Benefits	<ul style="list-style-type: none"> - Enhances architectural excitement - Creates dynamic and flexible interiors - Aligns structure with functional and aesthetic needs
Examples	<ul style="list-style-type: none"> - The Interlace (Singapore): Partial integration of structure and space - MahaNakhon (Bangkok): Innovative design yet lacking full structural coherence

For instance, structural engineering principles, such as adjusting member sizes in proportion to the stresses they bear, could be employed as an architectural strategy to define and organize internal spaces. Similarly, the legitimate differentiation of the structural system within a building could be used to facilitate spatial articulation and create varied, dynamic interior environments (Schumacher, 2014). Although these principles have been primarily applied to low-rise buildings, their extension to high-rise architecture offers a promising vision for the future. The concept of the “structural hybrid”, wherein the structure not only sustains but also shapes the architecture, holds immense potential for addressing the design challenges of high-rise buildings. By utilizing structure as an architectural element that defines space and generates excitement, structural hybrids represent the next step in the evolution of high-rise building typology.

Ultimately, while current projects such as The Interlace and MahaNakhon demonstrate the potential for spatial and structural innovation, their shortcomings in fully integrating these two aspects highlight the driving need for structural hybrids. These hybrids will enable structure to contribute to the architectural expression and functionality of buildings in ways that go beyond load-bearing, offering a more integrated, dynamic, and aesthetically engaging approach to high-rise design. Table 6 outlines the key challenges in achieving this integration and proposes strategic solutions for advancing the design of structural hybrids.

Table 6. Challenges and strategies in structural hybrids (prepared by the authors).

Challenge	Description	Proposed Strategies
Architectural-Structural Disconnection	Fragmented approach of architectural planning and structural flexibility limits spatial quality.	Collaborative design processes aligning with structural and architectural goals.
Repetitive Structural Systems	Uniform systems in traditional high-rise buildings constrain interior adaptability and spatial diversity.	Use of differentiated structural morphologies tailored to specific functional and spatial requirements.
Complexity in Design Integration	High-rise projects demand advanced coordination between structural engineers and architects to achieve synergy.	Explore structural form-finding techniques (e.g., stress-adaptive member sizing) to enhance spatial and functional integration.

While structural hybrids hold considerable promise, their implementation comes with notable challenges. The design of such systems often demands advanced computational modelling and highly specialized expertise, requiring close, seamless collaboration between architects and structural engineers, which can significantly extend project timelines and increase costs. Moreover, the complexity of these hybrid structures, which evolve in response to varied functional and aesthetic needs, may limit the flexibility of future adaptations or reconfigurations of interior spaces, as these solutions are often site-specific and deeply integrated into the building's core design. The pursuit of architectural innovation through structural integration could also lead to inefficiencies, as the structural system's complexity may outweigh the practical benefits, resulting in over-engineering or the use of non-standard materials and construction techniques. Furthermore, the untested long-term performance and maintenance of such systems, especially in high-rise buildings, introduces a level of risk, as their durability, adaptability, and ability to meet evolving needs over time remain uncertain. These factors contribute to the hesitation in fully adopting structural hybrids across the industry, making their widespread use more challenging despite their potential for redefining high-rise building design. Table 7 provides an overall comparison of structural hybrid expressions with traditional structural systems.

Table 7. Comparison of structural hybrid expressions with traditional structural systems (prepared by the authors).

Aspect	Traditional Structure	Structural Hybrid
Design Philosophy	Primarily focused on efficiency and functionality.	Focuses on both efficiency and architectural expression.
Role of Structure	Structure is a secondary element, designed to support the building.	Structure is an active design element, contributing to spatial and aesthetic qualities.
Architectural Integration	Architecture and structure are often isolated in the design process.	Architecture and structure are integrated, creating a cohesive design.
Flexibility	Limited flexibility, with repetitive floor plans and uniform structural elements.	Offers greater flexibility, with structural adaptations that respond to varying functional, spatial, and aesthetic needs.
Aesthetic Impact	Structure is mostly hidden, focusing on technical performance.	Structure plays an integral role in defining form and enhancing spatial experience.
Material Use	Standardized materials and construction techniques.	Use of innovative materials and construction methods tailored to both structural and aesthetic needs.
Adaptability	Difficult to adapt or modify once the structure is set.	Potential for more adaptability and future reconfiguration, although this depends on the specific design.
Collaborative Approach	Separate roles for architects and engineers, with limited interaction.	Close collaboration between architects and engineers, blending their expertise to form a unified design.
Long-Term Performance	Proven and reliable, with established methods and materials.	Less proven over time, with uncertainties regarding long-term performance, maintenance, and adaptability.

3. Conclusions

As urban populations grow and vertical cities expand, high-rise buildings have become central to contemporary architectural typologies. However, most high-rises globally rely on standardized, rectilinear designs inspired by Western templates that prioritize efficiency and aesthetics over spatial quality. This "one size fits all" approach results in a disheartening uniformity, with little regard for the unique cultural, environmental, and social contexts of urban centres. Such designs often depend on air-conditioned, closed systems and repetitive floor

plans, failing to address the pressing need for innovative, sustainable, and human-centric high-rise typologies.

The disconnection between architectural and structural design exacerbates this issue. Structural systems are frequently treated as secondary considerations, added only after the architectural form has been defined, which reduces the role of engineering in solving technical challenges. This siloed approach leads to uniform, rigid structural elements repeated throughout building heights, sacrificing flexibility and limiting opportunities for creative integration. While architects emphasize spatial experience and engineers focus on performance optimization, a lack of dialogue between these disciplines diminishes the potential for structural systems to shape space, guide movement, and enhance architectural expression.

Structural hybrids present a transformative alternative by seamlessly integrating structural systems into the architectural design process. These hybrids treat structure not merely as a load-bearing mechanism but as an active participant in shaping spatial and aesthetic qualities. By encouraging interdisciplinary collaboration and exploring new material and design innovations, hybrid typologies create high-rises that are more responsive to cultural, climatic, and functional contexts. This approach has the potential to redefine the future of high-rise buildings, moving away from uniformity toward a dynamic, integrated model that prioritizes both spatial richness and structural performance.

Future research on structural hybrids should delve deeper into their architectural, structural, and environmental potentials to redefine high-rise design. One promising direction involves the development of computational tools that foster collaboration between architects and engineers, enabling seamless integration of structure and spatial design from the conceptual phase. These tools could incorporate parametric and performance-based design methods to explore innovative geometries and structural configurations tailored to site-specific conditions. Additionally, interdisciplinary studies on material innovation -such as advanced composites, hybrid timber systems, and responsive materials -could further enhance the flexibility and sustainability of structural hybrids. Furthermore, case studies and pilot projects examining how cultural and climatic contexts influence hybrid structures could provide valuable insights, demonstrating how such typologies might challenge the global uniformity of high-rises. Finally, the integration of structural hybrids into urban planning frameworks could explore their potential to foster new forms of vertical community, addressing social and environmental challenges in the densification of urban centres.

Declaration of Ethical Standards

The article complies with national and international research and publication ethics.

Ethics Committee Approval was not required for the study.

Conflict of Interest

There was no conflict of interest between the authors during the research process.

Authors' Contributions

All authors contributed equally to the article.

Declarations

The authors take full responsibility for the content and any modifications made during this process.

No artificial intelligence-based tools or applications were used during the preparation of this study. The entire content of the study was produced by the authors in accordance with scientific research methods and academic ethical principles.

Originality Report

The article has been confirmed that it does not contain any plagiarism according to the originality report obtained from the iThenticate software.

Notes

This study is evaluated under the double-blind peer review system.

Please use livenarchjournal@ktu.edu.tr email address for submitting ethical statements.

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