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Investigating Space Utilization in Skyscrapers Designed with Prismatic Form

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Abstract: The enduring appeal of prismatic shapes, historically prevalent in office building designs, persists in contemporary skyscraper architecture, which is attributed particularly to their advantageous aspects concerning cost-efficiency and optimal space utilization. Space efficiency is a crucial factor in prismatic skyscraper design, carrying substantial implications for sustainability. However, the current academic literature lacks a complete exploration of space efficiency in supertall towers with prismatic forms, despite their widespread use. This paper seeks to address this significant gap by conducting a comprehensive analysis of data gathered from a carefully selected set of 35 case studies. The primary discoveries presented in this paper are outlined as follows: (i) average space efficiency stood at approximately 72%, covering a range that extended from 56% to 84%; (ii) average core to gross floor area ratio averaged around 24%, spanning a spectrum that ranged from 12% to 36%; (iii) the majority of prismatic skyscrapers utilized a central core approach, mainly customized for residential use; (iv) the dominant structural system observed in the analyzed cases was the outriggered frame system, with concrete being the commonly utilized material for the structural components; and (v) the impact of diverse structural systems on space efficiency showed no significant deviation, although differences in function led to variations in average space efficiency. The authors expect that these findings will provide valuable guidance, especially for architects, as they strive to enhance the sustainable planning of prismatic towers.

Keywords: supertall tower; prismatic skyscrapers; space efficiency; case studies

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1. Introduction

Due to global urban expansion and technological advancements, there has been a substantial rise in the construction of supertall towers, as evidenced by the exponential growth reported by [1–3]. Initial tall building designs were straightforward, favoring traditional shapes such as squares and rectangles [4].

Contemporary skyscrapers exhibit diverse atypical structures, including tapered, setback, or twisted forms [5,6]. However, prismatic configurations, characterized by rectangular and box-like shapes, remain prevalent, as exemplified by iconic structures like Marina 106 in Dubai and 432 Park Avenue (Figure 1) in New York [7–9]. Prismatic forms offer several advantages, including structural stability, cost-effective construction, efficient space utilization, flexibility for various functions, creative facade design opportunities, and floor plate efficiency [10].

In the context of supertall towers, the concept of space efficiency involves maximizing usable floor space, optimizing core space distribution, and selecting suitable structural systems and materials [11]. Despite extensive research on tall building design and construction [12–15], there is a notable lack of complete studies addressing spatial utilization in prismatic skyscrapers.

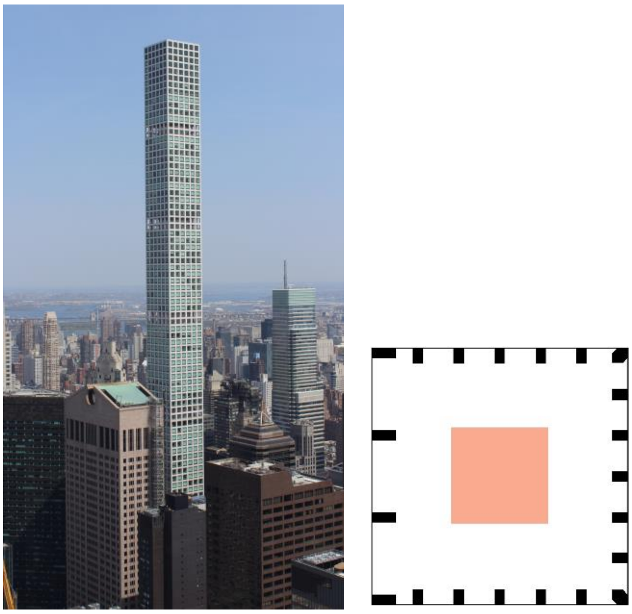


Figure 1. 432 Park Avenue (source: Wikipedia) with schematic floor plan (image created by authors).

Space efficiency is a significant factor in the discourse on supertall skyscrapers for several key reasons:

1. Urban density and land scarcity [16,17]: Cities, especially large metropolitan areas, face the constant challenge of limited space due to dense populations and high demand for land. Supertall skyscrapers ($\geq$300 m) offer a solution by maximizing vertical space and accommodating more people or functions within a smaller footprint. This is crucial in urban areas where land is at a premium.
2. Economic efficiency [18,19]: Efficient use of space allows for more revenue generation within a smaller area. Supertall skyscrapers often contain mixed-use spaces (like residential, commercial, and office), maximizing the economic output from a single building. This contributes to higher return on investment for developers and can drive economic growth in the surrounding area.
3. Sustainability and environmental impact [20,21]: Space efficiency can contribute to sustainability. By concentrating people and functions within a tall building, cities can reduce urban sprawl, lowering the need for additional infrastructure, transportation, and energy. This approach can help cities reduce their carbon footprint and environmental impact.
4. Vertical mixed-use development [22,23]: Supertall skyscrapers allow for mixed-use development on a vertical scale. This space efficiency enables cities to offer a variety of amenities, like offices, residences, retail, and recreational facilities, within a single structure. This concept aligns with the goal of creating '15 min cities', where essential services are easily accessible, reducing the need for extensive travel.
5. Aesthetics and urban design [24,25]: Space efficiency also plays a role in the aesthetics and overall design of cities. Supertall skyscrapers can create distinctive skylines and serve as architectural landmarks. Efficiently designed skyscrapers contribute to the city's identity and appeal, attracting tourism and boosting property values.

Overall, space efficiency is central to the success and sustainability of supertall skyscrapers. By optimizing vertical space and creating multifunctional environments, these buildings offer economic, social, and environmental benefits that can help address the challenges of modern urbanization.

The literature on space efficiency in buildings includes various studies, as detailed in the next section, with a broad focus on different building types, designs, and geographic locations. It covers key findings related to spatial efficiency in supertall towers, residential buildings, freeform structures, office towers, and mixed-use skyscrapers. However, the diversity of studies and their focus on a range of building typologies, including non-prismatic forms, may make it difficult to extract clear insights specifically about prismatic skyscrapers. Although some studies touch on prismatic forms, the reviewed literature could benefit from a more focused approach to understand how prismatic design elements affect space utilization. To address the need for research on space utilization in prismatic skyscrapers, the literature should delve deeper into this specific category, identifying common themes, challenges, and gaps in the current body of knowledge. This would provide a clearer understanding of the unique aspects of prismatic skyscrapers and their implications for spatial efficiency.

Our paper offers unique insights into the space efficiency of prismatic skyscraper designs, with a focus on supertall towers. This article fills a gap in existing academic literature, where space efficiency in prismatic forms has not been thoroughly explored, despite their common use. By analyzing data from 35 case studies, we present several key findings that set it apart from other research in this area, including comprehensive space efficiency and core to gross floor area ratio analyses, prevalent core planning approaches, dominant structural systems and materials, and the impact of structural systems and functions on space efficiency. These unique findings contribute valuable information to the field of skyscraper architecture, offering practical guidance for architects and engineers in their quest to create more sustainable and efficient prismatic skyscrapers.

This research, while excluding sustainable planning aspects due to data limitations, emphasizes the crucial role of space efficiency in enhancing financial returns, occupant well-being, and environmental sustainability in vertical urban environments. Given the comprehensive nature of concepts like circulation flow, space flexibility, and adaptability, which are extensive enough to merit individual research pursuits, this article intentionally excludes them from its scope. Additionally, due to the study's focus, proportional assessments of crucial building zones, such as the core, were employed, omitting consideration of the floor area dimensions of the prismatic towers as well as the structural elements, like columns and pillars. Furthermore, due to the restricted access to information on skyscrapers, particularly following the events of 9/11, and the lack of data, such as inter-story height and floor plan depth for many skyscraper cases, analyses related to these aspects could not be conducted.

This study anticipates providing valuable insights for architects, engineers, urban planners, investors, and stakeholders involved in the construction of prismatic buildings, influencing future design approaches for more effective and sustainable urban settings.

2. Literature Survey

The current scientific literature does not possess comprehensive research initiatives dedicated to attaining a complete grasp of the intricacies surrounding space efficiency in tall structures. Earlier investigations in this domain have been constrained in their scope, usually concentrating on a limited selection of tall buildings, although remarkable outliers can be identified within the extensive body of work carried out by [26,27].

Tuure and Ilgın [28] conducted a study utilizing information obtained from more than 50 Finnish mid-rise timber apartment buildings. The key results could be outlined as follows: 1. In analyzed cases, space utilization varied between around 78% and 88%, with a mean of about 80%. 2. Construction methods and structural materials related to shear walls did not show notable differences in terms of space efficiency.

Ilgın [29] conducted a thorough investigation into the spatial efficiency of 75 supertall buildings situated in Asia. The study's main findings can be outlined as follows: (a) the average spatial efficiency was 67.5%, with a range from 55% to 82%; (b) the mean ratio of core to gross floor area (GFA) was about 30%, varying between 14% and 38%. Additionally, Ilgın [30] focused on spatial efficiency in 40 tapered supertall towers, revealing the following key results: (i) the average spatial efficiency was around 72%, with fluctuations ranging from 55% to 84%; (ii) the average ratio of core to GFA was approximately 26%, spanning from 11% to 38%.

Goessler and Kaluarachchi [31] examined the influence of smart technologies on compact urban residences, with the goal of making them more adaptable and customized to special demands. The research assumed that the combination of adaptive residential design and technology could potentially improve space utilization two to three times more than conventional dwelling arrangements. The results showed that integrating adjustable technology can improve spatial efficiency by minimizing the necessity for individual physical zones assigned to different endeavors.

Ibrahimy et al. [32] assessed space utilization effectiveness in dwellings within Kabul City. The results of the investigation indicated that most residential structures do not comply with prescribed regulations and criteria regarding space utilization. This lack of conformity arises due to insufficient focus on the internal design process and a failure to comply with government building regulations.

In a recent investigation carried out by Okbaz and Sev [33], they undertook an examination involving 11 office towers featuring freeform designs, aiming to provide insights into space efficiency. Their thorough examination took into account a range of planning aspects, such as service core layout. The outcomes revealed that freeform towers exhibited a lower degree of spatial efficiency when contrasted with tapered shapes.

In a research effort conducted by Hamid et al. [34], interviews were carried out with Sudanese design companies, with the aim of exploring the concept of spatial efficiency in 60 residences. The study evaluated many features, such as the positioning of courtyards and the organization of circulation elements. The outcomes suggested that placing houses at the corners of the land plot led to the most effective utilization of space.

Suga [35] explored the domain of spatial efficiency. The study emphasized the positive effect of space-efficient planning in hotel projects, specifically emphasizing the effective organization of shared areas in relation to the size of guest rooms.

Ilgın [36] undertook a study on core layout and spatial efficiency in skyscrapers with office use. The research drew insights from an analysis of ten case studies to investigate key factors influencing the effects of service core design. The author recognized the ongoing evolution of modern service core design trends and presented essential design principles that consider these dynamic trends.

Ilgın [26] researched space efficiency in 44 office skyscrapers, concentrating on crucial architectural and structural planning factors. Simultaneously, a parallel endeavor focused on assessing space efficiency in 27 residential towers, employing similar planning criteria [27]. Additionally, Ilgın [37] conducted a study on the space efficiency of 64 skyscrapers that encompassed a mix of functions. The collective outcomes from Ilgın's studies revealed a prevailing preference for a central core layout, with outriggered frame systems commonly utilized as structural systems.

Arslan Kılınç [38] utilized regression analysis techniques to investigate the variables influencing the configuration of core and structural systems in prismatic towers. The study revealed a connection between the height of the building and the allotment of more extensive areas for both the load-bearing system and the core layout. However, no significant correlation was identified between spatial efficiency and the selection of materials.

Von Both [39] presented a method tailored for the early stages of planning, based on stakeholder analysis. This method assists in defining user functions related to processes and establishing clear functional interconnections. It promotes planners to actively explore potential improvements in terms of both area and spatial efficiency. This approach was demonstrated as an online tool, facilitating a design procedure that engages clients and interested parties.

Höjer and Mjörnell [40] examined the impact of digitalization on the dynamics of internal space use from a scientific standpoint. The discussion delves into the influence of policy measures in fostering a more resource-efficient utilization of space. By integrating concepts that endorse the flexible use of digitally improved areas and employing advanced methods, they propose a four-step building guide: the initial stage includes minimizing space requirements; the following stage highlights maximizing the utilization of already existing space; the third phase focuses on renovating and adapting current buildings to align with present-day needs; and the last stage revolves around the construction of new structures.

Zhang et al. [41] pioneered a methodology for designing a freeform building tailored for the Chinese cold regions. The results of their investigation revealed that, in contrast to a reference building featuring a cubic layout, the optimized free-form structure exhibited a significant increase in total solar radiation gain, surpassing 50%. This innovative approach not only demonstrated superior performance in harnessing solar energy but also showcased the potential for enhancing energy efficiency in cold climates through thoughtful design and form optimization.

Nam and Shim [42] directed their investigation toward assessing spatial efficiency in lofty structures, with specific emphasis on corner layouts and lease spans. The research disclosed that square-angled corner configurations had a detrimental impact on spatial efficiency. Conversely, lease spans were recognized as a noteworthy determinant affecting spatial efficiency, whereas corner incisions were noted to exert a negligible influence.

Sev and Özgen [43] embarked on an exhaustive examination of space efficiency, centering on 10 tall office edifices. Their inquiry considered diverse elements such as core configurations. The outcomes emphasized the crucial role of core arrangement and load-bearing systems in achieving optimal spatial efficiency. Core planning tactics displayed significant divergences contingent on user requirements, with the central core design emerging as the favored strategy for tall offices.

Saari et al. [44] conducted a detailed examination of the intricate relationship between spatial efficiency and the total costs associated with office towers. The research showed a substantial effect of better space efficiency in meeting the necessary criteria for ensuring interior climate comfort within these structures.

Lastly, Kim and Elnimeiri [45] assessed spatial efficiency ratios across a collection of ten mixed-use tall structures. They highlighted the pivotal influence of elevator optimization methods and the strategic distribution of operational spaces in augmenting spatial efficiency. Furthermore, they stressed the significance of aligning building design and structural systems as important features that substantially contribute to improved spatial efficiency.

The literature review underscores a discernible gap in scientific inquiry related to the spatial efficiency of skyscrapers, with previous research mainly concentrating on either operational features or architectural design. While works such as [31] emphasize functional considerations, and those like [15] delve into architectural design, a substantial void exists in comprehensive research addressing space efficiency in towers characterized by a prismatic form—this being one of the prevailing designs in supertall towers. This paper seeks to bridge this notable gap by delving into the specific challenges and opportunities associated with space optimization in tall and supertall buildings, particularly those featuring a prismatic architectural configuration. The aim is to contribute valuable insights to the academic discourse on building efficiency and design, shedding light on a critical aspect that has hitherto received limited attention in the scientific literature.

3. Methods

To investigate the concept of spatial effectiveness in prismatic skyscrapers, a case study approach was employed in evaluating projects within the built environment. The selected approach, widely acknowledged and embraced within the academic environment, facilitates the collection of both quantitative and qualitative data (Figure 2). This, in turn, enables a comprehensive examination of the field of study [46]. A thorough selection procedure was undertaken to identify and incorporate a total of 35 supertall towers characterized by their prismatic configurations, with each tower undergoing thorough scrutiny.

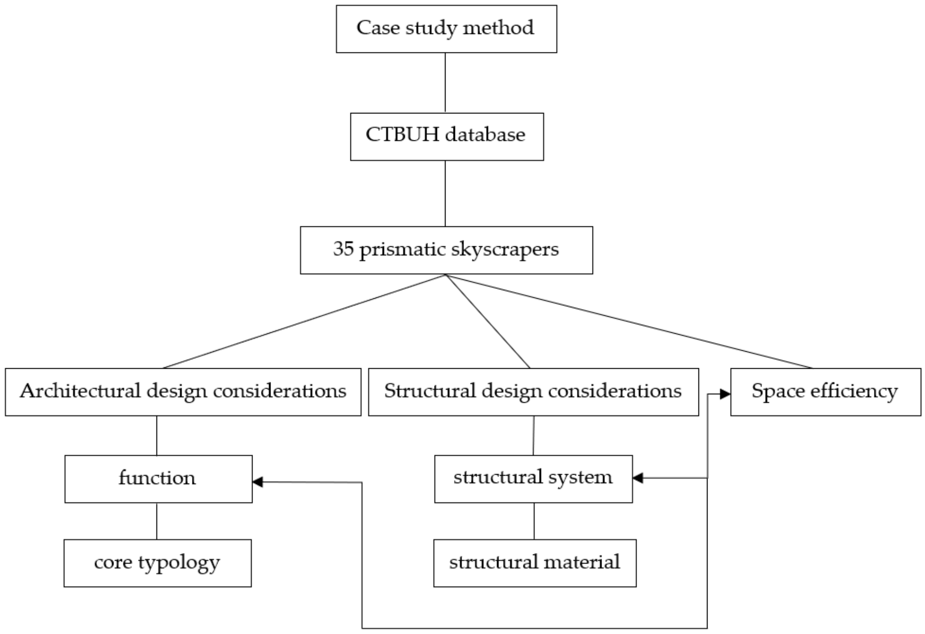


Figure 2. Flowchart of the methodology and process (image created by authors).

In the course of this study, a meticulous examination was conducted on a sample size comprising 35 cases, reflecting a comprehensive and geographically diverse distribution. This sample showcased a significant presence across various regions worldwide, with 17 towers situated in Asia, notably 12 of them located in China. The Middle East contributed 13 towers to the sample, while the United States featured 2 towers. Additionally, there was representation from Russia, Canada, and Australia, each contributing 1 tower, as meticulously detailed in Appendix A. It is imperative to underscore the stringent selection process employed during the case study curation, deliberately excluding supertall buildings lacking sufficient and readily available data on space efficiency or floor layouts, as evidenced in Appendices A–C. This methodological approach was adopted to uphold the integrity and reliability of the dataset, ensuring a focused and meaningful analysis of the 35 chosen cases, and thereby enhancing the validity of the study's findings.

It is worth underscoring that our study selected the above-mentioned cases as a diverse sample to evaluate space efficiency, considering various contextual factors like cultural, geographical, economic, and regulatory differences across different regions. Here's how these factors might have influenced the selection and ultimately the assessment of space efficiency:

- Geographical distribution: The sample was spread across several regions, with the largest concentration in Asia (17 towers), particularly in China (12 towers). This geographical variety allows the study to consider space efficiency across different environments, climates, and urban landscapes. This wide distribution contributes to a more comprehensive understanding of space usage and design trends.
- Cultural context: Cultural differences can impact architectural style, space allocation, and building purposes. For example, Asian skyscrapers may reflect different design philosophies and user needs compared to those in the Middle East or the United States. By including a broad cultural range, the study could account for these variations in design approach and space use.
- Economic factors: Economic conditions influence construction trends, land value, and investment in high-rise buildings. In regions like China and the Middle East, the economic boom and urbanization drive demand for tall structures. This sample's inclusion of economically diverse regions allows for an examination of how space efficiency correlates with economic growth.

- Regulatory environment: Building codes and zoning laws vary across countries and cities, affecting the design and use of skyscrapers. The sample's geographic spread includes areas with different regulatory frameworks, offering insight into how these regulations shape building construction and space efficiency.
- Regional specialization: Certain regions are known for their unique approach to skyscrapers, such as China's rapid urban development and the Middle East's focus on iconic high-rises. By including these specialized regions in the sample, the study can evaluate how these trends influence space efficiency.

Overall, the selection criteria for this study ensured a diverse mix of skyscrapers, allowing the analysis to consider multiple factors that can impact space efficiency. The geographical, cultural, economic, and regulatory variations within this sample provided a broad spectrum of contexts to better understand how these aspects affect the design and use of skyscrapers worldwide.

In a comprehensive effort, the authors rigorously analyzed the floor layouts of a wide range of prismatic supertall skyscrapers, encompassing typical floors. This meticulous method guaranteed the gain of dependable and accurate data, establishing a sturdy foundation for the assessment of spatial efficiency in the selected case studies. Additionally, in accordance with the established scholarly literature [47–49], the authors adopted the comprehensive categorization framework introduced by [27] for pivotal elements in architectural and structural design. This decision was driven by the detailed characteristics of these categories, as vividly delineated in Figure 3.

Core	**Structural system**	**Structural material**
Central core • central • central split	Shear-frame system • shear trussed frame • shear walled frame	Steel
Atrium core • atrium • atrium split	Mega core system	Reinforced concrete
	Mega column system	Composite
	Outriggered frame system	
External core • attached • detached • partial split • full split	Tube system • framed-tube • trussed-tube • bundled-tube	
	Buttressed core system	
Peripheral core • partial peripheral • full peripheral • partial split • full split		

Figure 3. Core, structural system, and material categorizations (image created by authors).

It is worth noting that a mega core system comprises a sizable core with significantly larger cross-sections than usual, extending continuously along the height of the building as the primary load-bearing element, as in the cases of Emirates Tower One and The Center. On the other hand, a mega column system is characterized by mega columns or shear walls featuring substantially larger cross-sections than typical elements. These elements run continuously along the height of the building, serving as the primary load-bearing components.

In this study, prismatic forms denote structures distinguished by congruent and parallel configurations at both extremities, showcasing indistinguishable facets and vertical axes accurately arranged orthogonally to the ground. This architectural arrangement guarantees uniform geometric ratios across the entirety of the edifice [39].

The formulation of an exact criterion for determining the number of floors or elevations that categorize a building as a supertall building remains a subject of continuous debate within the academic environment, lacking a universally accepted definition. Nonetheless, for the purposes of this research, the categorization of a structure as a supertall tower aligns with the norms established by the Council on Tall Buildings and Urban Habitat (CTBUH). According to this database, a supertall structure is defined as one with a height exceeding 300 m [50].

Space efficiency concerns the relationship between the net floor area (NFA) and GFA. Space efficiency holds considerable importance, particularly for investors, as it entails the effective utilization of floor plan areas to attain optimal returns on investment. The degree of spatial efficiency primarily hinges on various considerations, encompassing the choice of structural systems and materials, design, and the layout of slabs [51].

In the methodology of this study, the assessment of space efficiency was conducted by calculating the percentage of the net floor area to GFA, providing a quantitative measure of how effectively the available space is utilized. Simultaneously, the calculation of core over GFA involved determining the percentage of the service core to GFA, offering insights into the proportional allocation of space dedicated to the essential structural and service components within the overall building structure.

The calculation of space efficiency involves two key ratios [26,27]: NFA to GFA and core to GFA. NFA is determined by subtracting the service core area from GFA. This subtraction helps to isolate the functional areas where activities take place, excluding spaces dedicated to infrastructure and support services. The ratio of NFA to GFA provides a quantitative measure of how effectively the available floor area is utilized for actual use, reflecting the efficiency of space allocation.

The core to GFA ratio is another essential parameter in space efficiency calculations. It involves determining the proportion of GFA occupied by the service core, which encompasses essential facilities such as elevators, stairwells, utility rooms, and other central services. This ratio sheds light on the extent to which the building's infrastructure occupies valuable floor space, influencing overall efficiency.

Moreover, architectural voids, like atriums, play a significant role in space calculations. When computing NFA, these voids are deducted from GFA. This deduction accounts for areas within the building that may not contribute directly to functional spaces but add aesthetic or environmental value. The consideration of voids acknowledges the importance of both utilitarian and aesthetic aspects in evaluating space efficiency.

For comprehensive details and the specific outcomes of these calculations, readers are encouraged to refer to Appendix C. This section provides a deeper understanding of the methodology applied, ensuring transparency, and allowing stakeholders to assess the validity and reliability of the space efficiency metrics presented.

The foundational principles underpinning the design of prismatic supertall buildings and various other structures are deeply rooted in the intricate interplay of architectural and structural imperatives. Core planning emerges as a critical determinant, exerting a substantial influence on the arrangement of vertical mobility and the distribution of shafts, as extensively elucidated by [52]. Concurrently, building form assumes significance in shaping floor slab dimensions and configuration, as expounded by [43]. The structural system, as articulated by [26], occupies a pivotal role in dictating the dimensions and layout of structural members, while the choice of structural material, as delineated by [27], decisively impacts the dimensions of structural elements.

The comprehensive integration of these criteria, as outlined earlier, not only governs fundamental aspects such as floor slab dimensions, lease span, structural layout, and core arrangement/dimension, but also collectively contributes to the optimization of space efficiency, a conclusion underscored by prior research such as [27]. Considering these reflections, the focal point of this study lies in a meticulous examination of these four paramount parameters, seeking to augment our understanding of their intricate dynamics and implications within the context of 35 supertall office buildings. The ensuing detailed discussions aim to unravel the nuanced relationships and synergies among these variables, offering valuable insights for the advancement of space-efficient design practices in supertall structures.

4. Findings

4.1. Main Architectural Design Considerations: Function and Core Typology

In the examination of skyscraper functionalities, a comprehensive analysis was undertaken, focusing predominantly on residential developments, which constituted a substantial 43% of the entire sample. Mixed-use occupancy emerged as a significant contributor, accounting for 31% of the overall utilization, while office occupancy held a notable share at 26%, as visually represented in Figure 4.

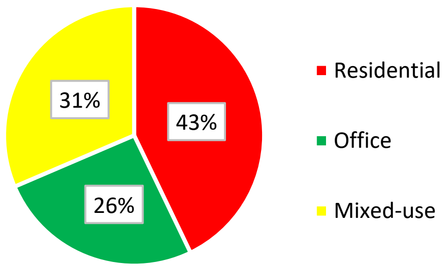


Figure 4. Prismatic supertall towers categorized by function (image created by authors).

The prevalence of prismatic forms in residential design was observed as a prominent trend, and this inclination can be attributed to the inherent advantages of simplicity in construction, practicality, and efficient interior space utilization, particularly when dealing with rectangular floor plans. Essentially, this trend suggests that these towering structures commonly adopt straightforward geometric designs in both their floor plans and elevations. The preference for regularity in architectural forms stems from the practical challenges associated with incorporating intricate shapes, such as twisted configurations, into the construction of skyscrapers, emphasizing the importance of practical considerations and efficiency in the design and realization of these iconic urban structures.

Within the myriad design possibilities explored for these towering structures, a distinctive preference emerged for prismatic supertall towers, with the central core strategy being the exclusive choice. This prevailing adoption of the central core approach finds its rationale in the compact and efficient structural design it affords. The strategic selection of this design not only enhances overall structural strength but also streamlines fire evacuation procedures, as detailed in [53].

In contrast, the infrequent utilization of an external core and the absence of a peripheral core can be attributed to the elongated circulation pathways they introduce, resulting in lengthier routes for fire evacuation. The central core strategy thus stands out as a judicious choice, prioritizing structural efficiency and safety considerations in the intricate design of these iconic skyscrapers.

Given that nearly every prismatic skyscraper in our study group, except for one—ADNOC Headquarters—features a central core design, this similarity precludes a direct comparative analysis of different core configurations. However, it is noteworthy to emphasize the significant impact that core layout and size can have on factors like space efficiency, aesthetics, and flexibility within these skyscrapers. Here's an analysis of how varying core sizes and configurations affect the usable space in skyscrapers:

- Proportionality to building height [37]: As skyscrapers rise in height, the core must often increase in size to accommodate more elevators, escalators, and stairwells. This requirement stems from the increased demand for vertical transportation and emergency egress. Consequently, larger cores reduce the proportion of usable space on each floor, affecting the building's overall efficiency.
- Space allocation [54]: A larger core, required to support taller buildings, generally results in less leasable space per floor. This reduction occurs because the core takes up a greater percentage of the floor plate, leading to smaller areas available for tenants. Conversely, smaller cores provide more usable space but may limit the building's height due to capacity constraints for elevators and other systems.

- Design efficiency [55]: Effective core design maximizes usable space by optimizing the arrangement of elevators, stairwells, and mechanical systems. A well-designed core minimizes wasted space, allowing for more efficient floor plans. However, inefficient or overly large core designs can lead to increased circulation space, further reducing the usable area.
- Flexibility and adaptability [56]: Core design affects the flexibility and adaptability of skyscrapers. A well-planned core allows for easier reconfiguration of interior spaces, facilitating tenant customization and adaptation to changing needs.
- Safety and accessibility [57]: The design of the core impacts safety and accessibility within skyscrapers. Adequate space for stairwells and emergency exits is crucial for safety, while the number and speed of elevators affect accessibility. Cores that prioritize safety and accessibility may need more space, potentially reducing the usable area on each floor.

Overall, the size and configuration of a skyscraper's core play a critical role in determining the amount of usable space within the building. Achieving a balance between structural requirements, safety, and usable space is key to successful skyscraper design.

4.2. Main Structural Design Considerations: Structural System and Structural Material

A discernible trend emerges in Figure 5, revealing that outriggered frame systems have secured a prevailing preference, constituting the selected structural configuration in an impressive 63% of instances. In stark contrast, tube systems occupy a comparatively lesser portion, amounting to 25% of the overall utilization.

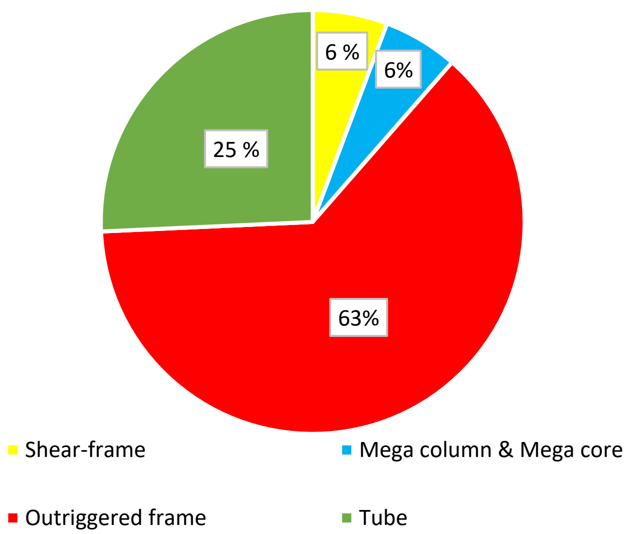


Figure 5. Prismatic supertall towers categorized by structural system (image created by authors).

The notable preference for outriggered frame systems can be ascribed to their inherent capacity to offer flexibility in arranging the perimeter columns. Consequently, architects benefit from enhanced creative freedom in shaping the building's outer structure, particularly with regard to achieving unobstructed external vistas. This expanded range of design possibilities, in turn, fosters the exploration of greater height potentials, rendering the outriggered frame system a pragmatic choice for the construction of prismatic skyscrapers. The selection of this structural system showcases a deliberate strategy to optimize both aesthetic and functional aspects, reinforcing its prominence in contemporary skyscraper design.

A clear pattern emerges, illustrated in Figure 6, indicating that reinforced concrete construction emerged as the most prevalent choice among the scrutinized case studies, constituting a significant 57% of the sample. This was closely followed by composite construction, which was observed in 40% of the cases analyzed. The widespread adoption of reinforced concrete in prismatic skyscrapers can be justified by its amalgamation of desirable attributes, including exceptional strength, longevity, fire resistance, architectural adaptability, damping properties, and cost-effectiveness [58,59]. This preference underscores a deliberate and informed decision-making process within the architectural and engineering realms, emphasizing the multifaceted advantages that reinforced concrete brings to the construction of prismatic skyscrapers, thereby reaffirming its status as a cornerstone material in contemporary vertical urban development.

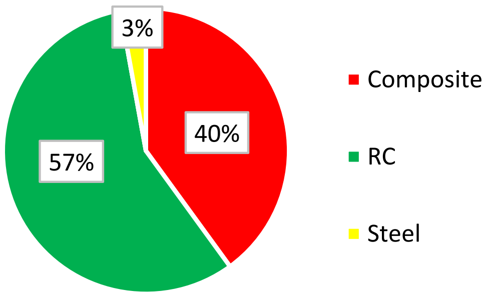
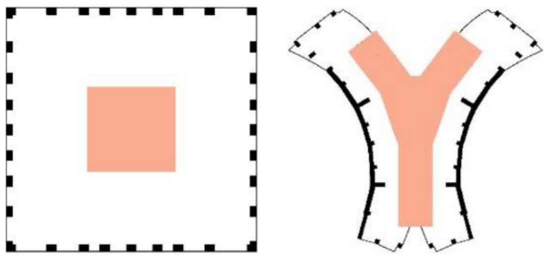


Figure 6. Prismatic supertall towers categorized by structural material (image created by authors).

4.3. Space Efficiency in Prismatic Supertall Towers

In this comprehensive study, which scrutinized 35 prismatic supertall towers, a thorough analysis revealed that the average space efficiency and the ratio of core area to GFA were calculated at approximately 72% and 24%, respectively. The study encapsulated a broad spectrum of values, showcasing the diverse nature of space utilization in prismatic supertall structures. The observed range extended from a minimum of 56% for space efficiency and 12% for the ratio of core area to GFA, to a maximum of 84% and 36%, respectively, as illustrated in Figure 7 and Appendix C. These findings provide a robust and nuanced understanding of the spatial dynamics inherent in prismatic supertall towers, offering valuable benchmarks for architects, engineers, and urban planners involved in the design and development of these iconic structures.



(**a**) (**b**)

Figure 7. Schematic floor plans of the prismatic skyscraper with the highest and lowest space efficiency, respectively: (**a**) Elite Residence, (**b**) LCT The Sharp Residential Tower A (images created by authors).

4.3.1. Interrelation of Space Efficiency and Function

Figure 8 shows the cumulative count of prismatic skyscrapers, illustrated as vertical bars on the right-hand axis and classified according to their respective functional properties. The chart offers additional information by incorporating blue dots to represent the space efficiency of each building within a particular function. On the other hand, red dots highlight the prismatic skyscraper with the highest space efficiency achieved accommodating the corresponding function. Moreover, the black bar serves as a visual indicator depicting the quantity of supertall towers within the sample set that utilize the same function.

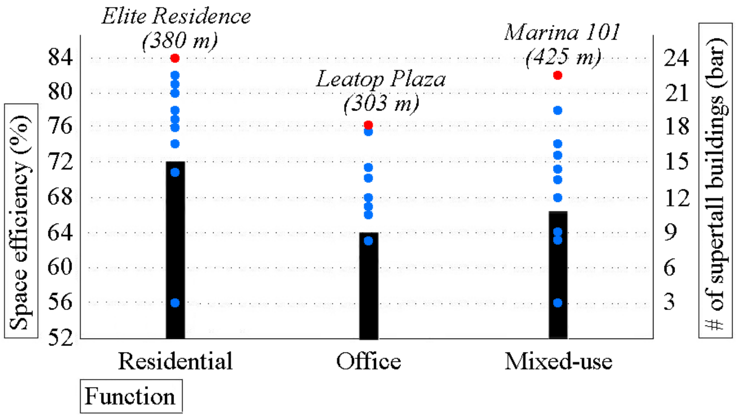


Figure 8. The interrelationship between space efficiency and function (image created by authors).

Within the realm of functions integrated into prismatic towers, residential usage has emerged as the predominant selection, finding implementation in 15 towers. The architectural landscape of these structures showcases noteworthy space optimization, with efficiency ratios spanning from 56% to an impressive 84% and averaging over 75%. This dominance of residential spaces underscores their effectiveness in maximizing usable floor area while maintaining functional integrity. In contrast, office utilization was less widespread, observed in nine supertall buildings, indicating a preference for these structures to cater to residential needs. Skyscrapers featuring mixed-use functionality, totaling eleven, demonstrated spatial efficiency ranging from 56% to 82%, with an average of approximately 69%. Figure 9 shows the schematic floor plans of the prismatic skyscrapers with the highest space efficiency achieved accommodating the corresponding function. This comprehensive breakdown not only highlights the prevalence of residential use as the favored functional preference in prismatic skyscrapers, but also underscores their efficacy in striking a balance between diverse functionalities, showcasing the adaptability and versatility of these architectural marvels in meeting the evolving demands of urban living and working environments.

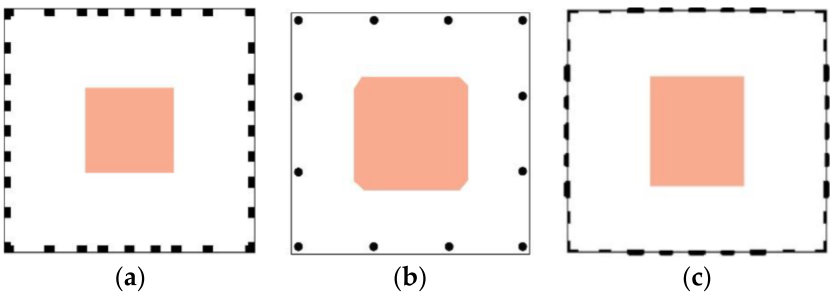


Figure 9. Schematic floor plans of the prismatic skyscrapers with the highest space efficiency achieved accommodating: (**a**) residential (Elite Residence), (**b**) office (Leatop Plaza), (**c**) mixed-use (Marina 101) functions (images created by authors).

4.3.2. Interrelation of Space Efficiency and Structural System

Figure 10 shows the cumulative count of prismatic skyscrapers, illustrated as vertical bars on the right-hand axis and classified according to their respective structural systems. The chart offers additional information by incorporating blue dots to represent the space efficiency of each structure within a particular structural system. On the other hand, red dots highlight the prismatic skyscraper with the highest space efficiency achieved employing the corresponding load-bearing system. Moreover, the black bar serves as a visual indicator depicting the quantity of supertall towers within the sample set that utilize the same load-bearing system.

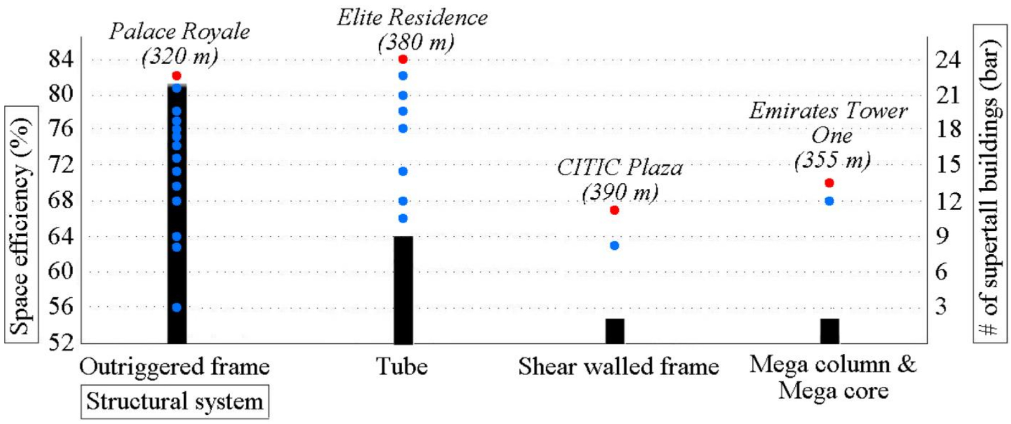


Figure 10. The interrelationship between space efficiency and structural system (image created by authors).

In the realm of structural systems employed in prismatic towers, outriggered frame systems have emerged as the dominant choice, being adopted in 22 towers. These structures demonstrated remarkable space utilization, spanning from 56% to 82%, with an average of around 72%. On the other hand, shear-walled frame systems and mega column and mega core systems were remarkably less common, being utilized in only four supertall buildings. Skyscrapers constructed using tube systems, totaling nine in number, exhibited spatial efficiency varying from 66% to 84%, with an average of about 72%. This detailed breakdown highlights the occurrence of outriggered frame systems as the preferred structural choice in prismatic skyscrapers, underscoring their effectiveness in achieving a balance between structural integrity and spatial efficiency. Figure 11 shows the schematic floor plans of the prismatic skyscrapers with the highest space efficiency achieved employing the corresponding structural system.

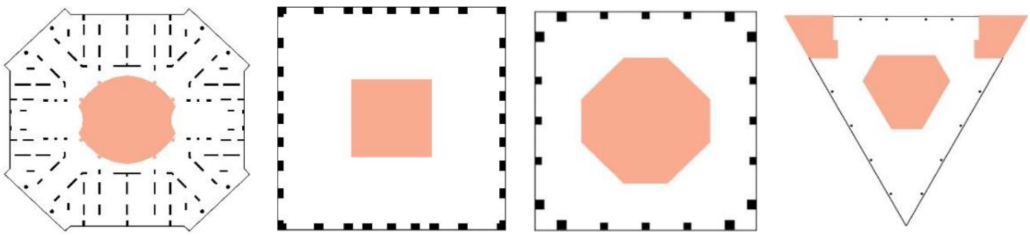


Figure 11. Schematic floor plans of the prismatic skyscrapers with the highest space efficiency achieved employing: (**a**) outriggered frame (Palace Royale), (**b**) tube (Elite Residence), (**c**) shear walled frame (CITIC Plaza), (**d**) mega column and mega core (Emirates Tower One) systems (images created by authors).

Extracting insights from the average values, it is reasonable to infer that the influence of different structural systems on spatial efficiency in prismatic towers does not exhibit substantial divergence. The uncommon use of shear-walled frame and mega column and mega core systems implies that establishing a scientifically meaningful correlation between the spatial efficiency of these buildings and their load-bearing systems may be challenging. The dominance of outriggered frame systems and the comparable average spatial efficiencies across various systems imply that, on average, these structural approaches contribute similarly to the spatial optimization of prismatic skyscrapers. It underscores the importance of considering other factors beyond load-bearing systems, such as architectural design and engineering innovations, in influencing spatial efficiency in tall building construction.

5. Discussion

The revelations emanating from this comprehensive research illuminate a diverse array of both shared characteristics and distinctive elements, presenting a nuanced panorama in contrast to prior inquiries, most notably the influential contributions of Oldfield and Doherty (2019) and the noteworthy work by Ilgın (2023b). Despite certain congruences in trends and results, which serve to bolster and affirm established notions within the field, this study delves further to unravel novel insights and intricate details that contribute to the enhancement of the prevailing knowledge base. The key outcomes could be succinctly summarized as follows:

1. The average space efficiency stood at approximately 72%, covering a range extended from 56% to 84%.
2. The average core area to GFA ratio averaged around 24%, spanning a spectrum that ranged from 12% to 36%.
3. The majority of prismatic skyscrapers utilized a central core layout, mainly customized for residential use.
4. The dominant structural system observed in the analyzed cases was the outriggered frame system, with concrete being the commonly utilized material for the structural components.
5. The effect of diverse structural systems on spatial efficiency in prismatic towers did not demonstrate significant deviation, although variations in functions resulted in differences in average space efficiency.

Aligned with the foundational study by [60], which established a spatial efficiency benchmark of 75% for high-rise buildings, it becomes apparent that prismatic towers deviate from this standard, demonstrating an average space efficiency of 72%. Building upon this insight, recent research conducted by [27,39] delves into the realm of office and mixed-use towers, revealing an average space efficiency of 71%, further falling short of Yeang's prescribed benchmark [60]. The underlying factors contributing to these disparities primarily stem from two crucial elements: the size of the core and the size of load-bearing elements within these towering structures. This empirical evidence not only underscores the enduring relevance of Yeang's benchmark but also highlights the significance of considering specific architectural features in achieving optimal space efficiency within the context of modern skyscraper design.

The challenges to achieving optimal space efficiency in supertall towers can be ascribed to two principal factors. Firstly, the service core area, housing essential utilities like elevators, staircases, and mechanical systems, often consumes a considerable portion of the available space within a skyscraper. In prismatic skyscrapers and those scrutinized by Ilgın, variations in the proportion or inefficient organization of this core area can diminish the usable space within the building.

Secondly, the structural elements of these towering structures play a pivotal role in determining space efficiency. As skyscrapers ascend to greater heights, the necessity for more substantial structural components arises, in order to support their weight and withstand external forces like wind and seismic activity. These structural elements, when not optimized for space efficiency, can occupy a significant amount of space, directly impacting the overall efficiency of the floorplates. Therefore, the interplay between the dimensions of the service core area and the size of load-bearing elements emerges as a critical consideration in the pursuit of enhancing space efficiency in contemporary skyscraper design.

Proactively tackling the identified challenges in future skyscraper design and construction holds the potential to be transformative, potentially surpassing Yeang's established space efficiency standard. This imperative task encompasses the exploration and implementation of innovative approaches to core design, emphasizing more compact and efficient layouts that minimize the impact of essential utilities on usable space. Furthermore, pivotal advancements in structural engineering are required, aiming to diminish the spatial footprint of load-bearing elements in these towering structures. The pursuit of heightened space efficiency in tall buildings extends beyond mere compliance with standards; it resonates with broader sustainability and resource optimization goals. Such endeavors not only contribute to a more ecologically conscious urban environment but also carry tangible benefits for the economic viability and functionality of these iconic structures. By strategically addressing spatial inefficiencies, future skyscrapers can emerge as paragons of architectural and engineering ingenuity, seamlessly integrating environmental responsibility with practical utility.

Building upon the insightful findings from the studies conducted by [27,61], a clear pattern emerges, indicating that the central core strategy has established itself as the preferred choice among the diverse array of buildings analyzed in various case studies. This design methodology entails placing a central core within the building, serving as the hub for essential services such as elevators and utilities while simultaneously providing structural support for the entire skyscraper. The predilection for this particular design strategy can be attributed to the several key advantages it presents.

Firstly, central core design proves instrumental in improving the utilization of available floor space. Through the strategic consolidation of utilities and vertical transportation systems within a central area, this design approach liberates significant space on the periphery of the building, facilitating more expansive areas for office or residential use. This thoughtful spatial arrangement enhances the overall efficiency of the structure, effectively maximizing the functional potential of each floor.

Secondly, central core design goes beyond space optimization by playing a pivotal role in enhancing structural stability [62–64]. By providing a robust and efficient load-bearing system, particularly crucial in the context of tall buildings, this design strategy ensures the skyscraper's resilience to various external forces. This structural stability is of paramount importance for guaranteeing the safety of occupants and maintaining the overall integrity of the skyscraper, especially in regions prone to seismic activity or characterized by high winds.

To achieve optimal space efficiency and strategic core location in prismatic skyscrapers, architects and engineers must account for several critical factors. Building use dictates the specific needs for core placement, with office structures often benefiting from centralized cores to facilitate efficient elevator traffic and centralized utilities, whereas residential buildings may opt for perimeter cores, to allow for more flexible apartment layouts and greater privacy. The core's placement also plays a pivotal role in structural stability; central cores generally provide a more evenly distributed structural load, enhancing the building's resistance to lateral forces such as wind and seismic activity, while perimeter cores may necessitate additional reinforcement and complex engineering solutions. Elevator traffic flow is another key consideration, as centralized cores tend to streamline elevator operations, reducing wait times and optimizing traffic patterns within the building. In contrast, perimeter cores might lead to longer wait times and more complex routing. Flexibility and adaptability are also impacted by core location; a centrally located core can allow for more straightforward reconfiguration of interior spaces over time, while a perimeter core may restrict such flexibility due to fixed corridors and infrastructure. Thus, the selection of the service core location requires a nuanced approach, blending architectural design, structural engineering, and operational efficiency to meet the unique demands of each building's purpose while maintaining a robust and adaptable framework for future developments.

Regarding structural systems and materials, the prevalence of outriggered frame systems and composite use within the case studies underscores their effectiveness in contemporary skyscraper design. Outriggered frame systems involve horizontal and vertical trusses or braces that connect the central core to the building's perimeter, distributing forces and mitigating sway [65–68]. This system enhances the building's structural performance and stability.

Moreover, the incorporation of composite materials, notably concrete and steel, in the construction of skyscrapers stands as a testament to the unparalleled strength and versatility these materials confer. Composite constructions represent a sophisticated synergy between different materials, harnessing the unique properties of each to create structures that excel in both structural integrity and space utilization [69–73]. The combination of concrete, prized for its compressive strength, and steel, celebrated for its tensile strength, results in a composite that not only enhances the load-bearing capacity of the skyscraper but also allows for the creation of expansive and open interior spaces. This utilization of composite materials, with their inherent durability and adaptability, contributes significantly to the overall efficiency and safety of tall buildings.

Space efficiency and function in architectural design are critical factors for sustainability and resource management, particularly in high-density urban environments. The examination of prismatic towers reveals that residential usage is the preferred choice for achieving higher space efficiency, largely because these structures focus on maximizing livable space with streamlined designs. The prevalence of residential usage in 15 out of 35 towers, with space efficiency ratios ranging from 56% to 84% and averaging over 75%, indicates a scientifically grounded trend toward designs that optimize spatial utilization. This efficiency is attributed to residential towers' minimal shared spaces, reducing infrastructure overhead and allowing for more consistent and adaptable floor plans. The relatively lower efficiency in office towers, observed in nine supertall buildings, is due to their need for more communal areas such as meeting rooms, lobbies, and shared facilities, which inherently limit usable floor space. Meanwhile, mixed-use towers, encompassing 11 buildings with space efficiency ranging from 56% to 82% and an average of about 69%, offer a balance between versatility and efficiency, as they integrate multiple functions like residential, office, and commercial spaces within a single structure. From a broader scientific perspective, this analysis suggests that residential designs tend to be more resource-efficient, leading to greater sustainability in urban planning. This insight has implications for architects and city planners aiming to create functional, efficient, and environmentally conscious urban spaces that meet the needs of growing populations while reducing the environmental footprint.

It is worth discussing that the conversion of prismatic skyscrapers from office to residential use is a complex undertaking that poses numerous challenges regarding space efficiency [74–76]. Office skyscrapers often feature expansive floor plans with centralized HVAC (Heating, Ventilation, and Air Conditioning), plumbing, and electrical systems designed for open workspaces. To convert these structures into residential units, developers must redesign the layout to create smaller, self-contained apartments, which requires the strategic partitioning and re-engineering of building systems. This re-engineering often involves installing individualized systems for each unit without compromising the building's structural integrity. Compliance with residential building codes adds another layer of complexity, as it often requires new fire safety measures, accessibility features, and additional stairwells or elevators, which can reduce usable space. Moreover, residential conversions necessitate the creation of common spaces, like gyms, laundry rooms, and recreational areas, requiring efficient multi-use designs to maximize space. Rooftop areas, lobbies, and basements might be repurposed to meet these needs without overwhelming the building's structure. Financially, the high cost of conversion must be balanced with the anticipated market demand for residential units. Developers must ensure that the resulting apartments are both attractive and profitable, considering unit sizes and amenities that cater to a broad range of potential residents. This also entails aesthetic transformations to shift from a corporate to a residential atmosphere, often involving substantial changes to the building's exterior and interior design to make it more inviting for residents. Ultimately, successful transformation requires an integrated approach, combining technical, regulatory, and market-driven considerations to ensure a seamless transition from office to residential use.

The relationship between space efficiency and the choice of structural system in prismatic skyscrapers is critical to the building's functional and financial success. Outriggered frame systems, characterized by horizontal beams that connect a central core to the building's outer columns, have emerged as a dominant choice due to their inherent spatial advantages. This system's design enables large, open floor plans by strategically transferring loads across the structure, thereby maximizing usable interior space. With spatial efficiency ranging from 56% to 82%, and an average of about 72%, outriggered frame systems are optimal for developers aiming to maximize leasable or sellable space while ensuring structural stability against wind and seismic forces. In contrast, other structural systems like shear-walled frames and mega column and mega core designs, though providing robust stability, typically result in a larger building core and thicker walls, reducing the amount of the open floor area available for occupancy. These systems are employed in scenarios where additional strength is prioritized over spatial flexibility, limiting their application in space-conscious designs. Tube systems, which use a grid of perimeter columns and beams to create a rigid shell, offer a similar space efficiency to outriggered systems, with a range of 66% to 84%. They achieve stability through this external framework, allowing for more flexible interior layouts. However, the optimal balance of space efficiency and structural resilience still seems to favor outriggered frame systems in prismatic towers. This observation suggests that, when designing skyscrapers, architects and engineers are increasingly valuing structural systems that offer both stability and high spatial efficiency, with outriggered frame systems providing a robust solution for this balance.

In the realm of future research endeavors, there is a promising avenue for exploration that involves a comprehensive examination of alternative prevalent tall building configurations, particularly focusing on innovative designs such as freeform structures. Conducting comparative analyses within this context could yield significant insights into the correlation between building form and space efficiency. Moreover, future investigations in this domain may delve into the influence of geographical location and cultural inclinations on space utilization and design preferences, specifically in prismatic skyscrapers. Exploring these aspects through a cross-regional comparative analysis has the potential to unveil divergences in sustainable architectural methodologies and their adaptability in diverse environmental settings. This prospective research trajectory not only contributes to advancing our understanding of tall building dynamics but also holds implications for shaping more contextually responsive and sustainable urban environments, emphasizing the importance of cultural and geographical factors in the evolving landscape of architectural design and urban planning.

The use of alternative materials in prismatic skyscraper construction could lead to significant changes in space efficiency. Materials such as steel, timber, or composites offer unique benefits and challenges. For example, steel [77–79]: Known for its high strength-to-weight ratio, steel allows for thinner columns and beams, potentially increasing space efficiency. Studies on hybrid designs (concrete cores with steel framing) could shed light on the optimal balance between these materials. Timber [80–82]: As engineered wood products like cross-laminated timber (CLT) gain popularity, research into their use in tall buildings is growing. Timber's lighter weight and environmental benefits may offer new possibilities for space-efficient designs. Composites [83,84]: Advanced composite materials, such as carbon-fiber reinforced polymers, offer high strength with reduced weight. Further research into their application in skyscraper construction could reveal their potential for space efficiency. Beyond space efficiency, the environmental impact of concrete and alternative materials is a key consideration. Concrete production is associated with high carbon emissions, while materials like timber and composites may offer more sustainable alternatives. Studies on the life cycle assessment of various materials, including their carbon footprint, recyclability, and durability, are crucial for making informed choices in skyscraper construction. Further studies into the use of concrete and alternative materials in prismatic skyscrapers should focus on optimizing space efficiency while considering environmental sustainability. By exploring high-performance concrete, innovative structural designs, and alternative materials like steel, timber, and composites, researchers can identify new pathways for constructing skyscrapers that are both efficient and environmentally conscious.

The authors conscientiously recognize the intrinsic limitations within this study. Data analysis was restricted to a sample of 35 supertall towers with prismatic configurations.

Recognizing this constraint, future investigations could significantly enhance the robustness of the findings by expanding the dataset to include a broader and more representative range of case study buildings. This expansion would facilitate a more comprehensive and persuasive analysis, providing a richer understanding of the relationships under scrutiny. Moreover, to improve the applicability of the research, forthcoming studies might consider incorporating towers below the 300 m threshold. This inclusive approach would enable the formation of multiple subgroups, allowing for a more nuanced and detailed examination and interpretation of the data, ultimately contributing to a more holistic comprehension of the complex interplay between building characteristics and spatial efficiency in the context of skyscrapers.

6. Conclusions

Modern prismatic skyscrapers primarily appear as residential complexes characterized by their central core approach, employing outriggered frame systems constructed with concrete. The pursuit of improving space efficiency in these skyscrapers is complex. In this context, the size of elements pertaining to the core, such as circulation components, and the structural system members, become crucial. However, with careful selection, the load-bearing system and materials can positively impact spatial efficiency. Architects assigned to design skyscrapers must adeptly harmonize considerations pertaining to sustainability and functionality within this framework. Achieving such an equilibrium enables the development of unique and ecologic prismatic structures that embody the tenets of modern planning and environmental responsibility.

Expanding on the sustainability implications of these findings, optimizing space efficiency in skyscraper design directly contributes to reducing the environmental footprint. A high average space efficiency of 72% indicates that skyscrapers can achieve significant resource conservation by minimizing wasted space, ultimately reducing the need for additional construction materials and associated carbon emissions. The core area to GFA ratio, averaging 24%, suggests that careful planning of central building infrastructure can optimize space, which could lead to more energy-efficient designs. This aligns with sustainability goals by promoting compact urban development, potentially reducing urban sprawl and its environmental impact. The structural systems identified, particularly the outriggered frame system with concrete, raise sustainability concerns due to concrete's high carbon footprint. Given this, exploring alternative materials such as timber or recycled composites, and incorporating advanced technologies to reduce concrete's environmental impact, could be key to advancing sustainability in skyscraper design. Additionally, the use of a central core layout in prismatic skyscrapers, primarily for residential purposes, opens opportunities for integrating mixed-use functions, which supports sustainability by creating self-contained vertical communities. This reduces transportation needs and encourages a more sustainable urban lifestyle. Combining these design strategies with passive design elements, like maximizing natural light and ventilation, and utilizing renewable energy sources, such as solar or wind, can further improve the sustainability profile of skyscrapers. Overall, a holistic approach that combines spatial efficiency, innovative materials, and energy-efficient systems is critical for advancing sustainability in the design and construction of prismatic skyscrapers.

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Data Availability Statement: The data presented in this study are available in this article.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Supertall Prismatic Buildings

#	Building Name	Country	City	Height (Meters)	# of Stories	Completion Date	Function
1	Changsha IFS Tower T1	China	Changsha	452	94	2018	M
2	Marina 106	UAE	Dubai	445	104	OH	R
3	Marina 101	UAE	Dubai	425	101	2017	M
4	432 Park Avenue	United States	New York	425	85	2015	R
5	Princess Tower	UAE	Dubai	413	101	2012	R
6	LCT The Sharp Landmark Tower	South Korea	Busan	411	101	2019	M
7	23 Marina	UAE	Dubai	392	88	2012	R
8	CITIC Plaza	China	Guangzhou	390	80	1996	O
9	Shum Yip Upperhills Tower 1	China	Shenzhen	388	80	2020	M
10	Autograph Tower	Indonesia	Jakarta	382	75	2022	M
11	Elite Residence	UAE	Dubai	380	87	2012	R
12	Central Plaza	China	Hong Kong	374	78	1992	O
13	Sino Steel International Plaza T2	China	Tianjin	358	83	OH	O
14	II Primo Tower 1	UAE	Dubai	356	79	UC	R
15	Emirates Tower One	UAE	Dubai	355	54	2000	O
16	The Torch	UAE	Dubai	352	86	2011	R
17	The Center	China	Hong Kong	346	73	1998	O
18	NEVA TOWERS 2	Russia	Moscow	345	79	2020	R
19	ADNOC Headquarters	UAE	Abu Dhabi	342	65	2015	O
20	LCT The Sharp Residential Tower A	Korea	Busan	339	85	2019	R
21	LCT The Sharp Residential Tower B	Korea	Busan	333	85	2019	R
22	Hon Kwok City Center	China	Shenzhen	329	80	2017	M
23	Deji Plaza	China	Nanjing	324	62	2013	M
24	Q1 Tower	Australia	Gold Coast	322	78	2005	R
25	Nina Tower	China	Hong Kong	320	80	2006	M
26	Palace Royale	India	Mumbai	320	88	OH	R
27	New York Times Tower	United States	New York	319	52	2007	O
28	Chongqing IFS T1	China	Chongqing	316	63	2016	M
29	Shenzhen Bay Innovation and Technology Centre Tower 1	China	Shenzhen	311	69	2020	O
30	The One	Canada	Toronto	308	85	UC	R
31	Amna Tower	UAE	Dubai	307	75	2020	R
32	Noora Tower	UAE	Dubai	307	75	2019	R
33	Burj Rafal	Saudi Arabia	Riyadh	307	68	2014	M
34	Leatop Plaza	China	Guangzhou	303	64	2012	O
35	Supernova Spira	India	Noida	300	80	OH	M

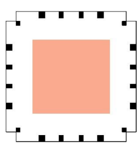
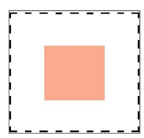
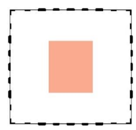
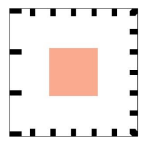
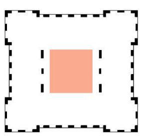
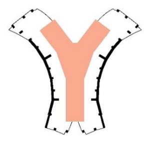
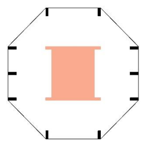
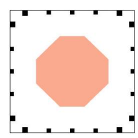
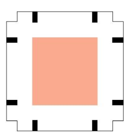
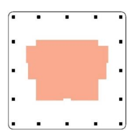
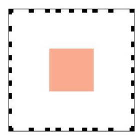
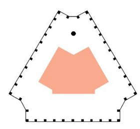
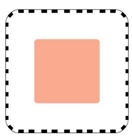
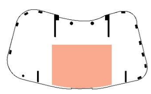
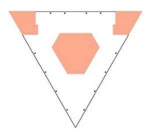
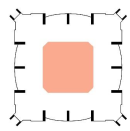
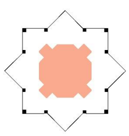
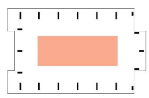
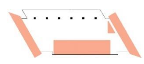
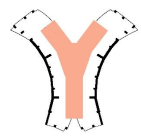
Note on abbreviations: 'M' indicates mixed-use; 'R' indicates residential; 'O' indicates office; 'UAE' indicates the United Arab Emirates; 'OH' indicates On hold; 'UC' indicates Under construction.

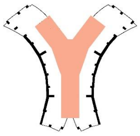
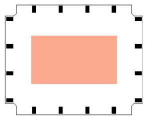
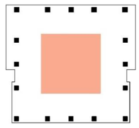
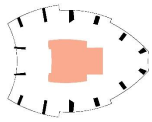
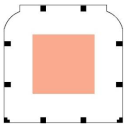
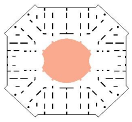
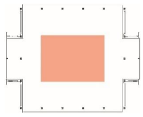
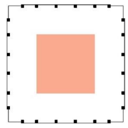
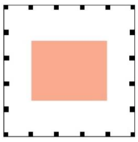
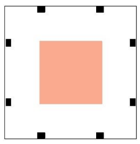
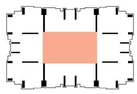
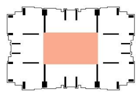
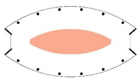
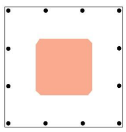
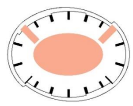
Appendix B. Supertall Prismatic Buildings by Core Type, Building Form, Structural System, and Structural Material

#	Building Name	Core Type	Structural System	Structural Material
1	Changsha IFS Tower T1	Central	Outriggered Frame	Composite
2	Marina 106	Central	Framed-tube	RC
3	Marina 101	Central	Framed-tube	RC
4	432 Park Avenue	Central	Framed-tube	RC
5	Princess Tower	Central	Framed-tube	RC
6	LCT The Sharp Landmark Tower	Central	Outriggered Frame	RC
7	23 Marina	Central	Outriggered frame	RC
8	CITIC Plaza	Central	Shear walled frame	RC
9	Shum Yip Upperhills Tower 1	Central	Outriggered Frame	Composite
10	Autograph Tower	Central	Outriggered Frame	Composite
11	Elite Residence	Central	Framed-tube	RC
12	Central Plaza	Central	Trussed-tube	Composite
13	Sino Steel International Plaza T2	Central	Framed-tube	Composite
14	Il Primo Tower 1	Central	Outriggered frame	RC
15	Emirates Tower One	Central	Mega column	Composite
16	The Torch	Central	Outriggered frame	RC
17	The Center	Central	Mega column	Composite
18	NEVA TOWERS 2	Central	Outriggered frame	RC
19	ADNOC Headquarters	External	Shear walled frame	RC
20	LCT The Sharp Residential Tower A	Central	Outriggered frame	RC
21	LCT The Sharp Residential Tower B	Central	Outriggered frame	RC
22	Hon Kwok City Center	Central	Outriggered Frame	Composite
23	Deji Plaza	Central	Outriggered Frame	Composite
24	Q1 Tower	Central	Outriggered frame	RC
25	Nina Tower	Central	Outriggered Frame	RC
26	Palace Royale	Central	Outriggered frame	RC
27	New York Times Tower	Central	Outriggered frame	Steel
28	Chongqing IFS T1	Central	Outriggered Frame	Composite
29	Shenzhen Bay Innovation and Technology Centre Tower 1	Central	Framed-tube	Composite
30	The One	Central	Outriggered frame	Composite
31	Amna Tower	Central	Outriggered frame	RC
32	Noora Tower	Central	Outriggered frame	RC
33	Burj Rafal	Central	Outriggered Frame	Composite
34	Leatop Plaza	Central	Trussed-tube	Composite
35	Supernova Spira	Central	Outriggered Frame	RC

Note on abbreviation: 'RC' indicates reinforced concrete.

Appendix C. Prismatic Supertall Buildings by Floor Plan with Space Efficiency and Core/GFA Ratio (Images Created by Authors)

Building Name							
Space Efficiency*				Core/GFA Ratio**			
Changsha IFS Tower T1		**Marina 106**		**Marina 101**		**432 Park Avenue**	
63%	34%	78%	20%	82%	16%	80%	14%
							
Typical floor		Typical floor		Typical floor		Typical floor	
Princess Tower		**LCT The Sharp Landmark Tower**		**23 Marina**		**CITIC Plaza**	
82%	12%	56%	36%	81%	17%	67%	22%
							
Typical floor		Typical floor		Typical floor		Typical floor	
Shum Yip Upperhills Tower 1		**Autograph Tower**		**Elite Residence**		**Central Plaza**	
64%	33%	68%	31%	84%	12%	66%	25%
							
Typical floor		Typical floor		Typical floor		Typical floor	
Sino Steel International Plaza T2		**Il Primo Tower 1**		**Emirates Tower One**		**The Torch**	
68%	27%	71%	28%	70%	30%	74%	22%
							
Typical floor		Typical floor		Typical floor		Typical floor	
The Center		**NEVA TOWERS 2**		**ADNOC Headquarters**		**LCT The Sharp Residential Tower A**	
68%	29%	77%	22%	63%	36%	56%	36%
							
Typical floor		Typical floor		Typical floor		Typical floor	

LCT The Sharp Residential Tower B		**Hon Kwok City Center**		**Deji Plaza**		**Q1 Tower**	
56%	36%	70%	28%	73%	24%	78%	17%
							
Typical floor		Typical floor		Typical floor		Typical floor	
Nina Tower		**Palace Royale**		**New York Times Tower**		**Chongqing IFS T1**	
71%	27%	82%	14%	75%	25%	74%	25%
							
Typical floor		Typical floor		Typical floor		Typical floor	
Shenzhen Bay Innovation and Technology Centre Tower 1		**The One**		**Amna Tower**		**Noora Tower**	
71%	26%	76%	22%	77%	17%	77%	17%
							
Typical floor		Typical floor		Typical floor		Typical floor	
Burj Rafal		**Leatop Plaza**		**Supernova Spira**			
78%	21%	76%	22%	63%	33%		
							
Typical floor		Typical floor		Typical floor			

Space efficiency*: calculated as the ratio of the net floor area [obtained by subtracting the service core (the pink area on the floor plan) and structural elements from GFA] to GFA. Core/GFA**: calculated as the ratio of the service core (the pink area on the floor plan) to GFA.

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