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Space Efficiency in Tall Hotel Towers

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Abstract: Maximizing spatial utilization within tall buildings stands as a paramount planning consideration for ensuring project feasibility, particularly accentuated ins the context of hotel constructions. To date, no comprehensive study has addressed this issue while considering crucial architectural and structural planning factors. This article fills this gap by using a case study method based on data from 31 contemporary tall hotel towers. The findings revealed several key points: (i) central core typology was mostly utilized; (ii) prismatic buildings were the most prevalent forms; (iii) shear-walled frame systems were predominantly employed; (iv) concrete was the preferred choice for hotel construction; (v) the average space efficiency and the ratio of core area to gross floor area (GFA) averaged 81.2% and 16%, respectively; (vi) the range changed from a minimum of 70% to 4% to a maximum of 94% to 28%; and (vii) space efficiency showed an inverse relationship with the height of the building. It is anticipated that this paper will assist architects and structural engineers as well as builders involved in the planning of hotel developments.

Keywords: tall hotel buildings; space efficiency; form; core planning; structural system and material

1. Introduction

Tall buildings stand as iconic symbols within urban landscapes across the globe, representing architectural feats that seamlessly blend form and function [1]. These towering structures, often punctuating skylines with their sleek silhouettes, embody the pinnacle of human ingenuity and engineering prowess [2–4]. As cities continue to expand and urban populations swell, the need for efficient land utilization becomes increasingly paramount [5]. Rapid urbanization places immense pressure on limited land resources, necessitating strategic planning and innovative solutions to accommodate growing populations while minimizing environmental impact [6].

In the realm of tall building design, space efficiency emerges as a critical factor, particularly when considering hotels. Efficient space utilization not only influences the initial conception of such structures but also significantly impacts their ongoing operational success. As urban landscapes become increasingly congested, the vertical expansion of buildings offers a practical solution to the challenge of limited land availability [7–9]. Tall hotels, therefore, must optimize every square foot of space, from the layout of guest rooms and common areas to the integration of amenities and services [10].

As the hospitality industry evolves in response to dynamic urbanization trends and technological progress [11], the importance of space-efficient tall hotel buildings becomes increasingly pronounced. By leveraging interdisciplinary expertise and embracing innovative approaches, stakeholders in the hotel development sector can unlock new avenues for enhancing spatial functionality, economic value, and environmental sustainability in vertical hospitality atmospheres [12].

The notion of space efficiency encompasses the optimal utilization of available space to accommodate various functions while maximizing user experience and operational effectiveness [13]. In the realm of tall hotels, achieving space efficiency requires a multifaceted

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approach that integrates architectural ingenuity, engineering innovations, and technological advancements [14]. Through strategic space allocation and innovative solutions, tall hotels can elevate guest satisfaction, streamline operations, and contribute to sustainable urban development [15].

In space efficiency research, [16] examined mid-rise timber structures in Finland, showing rates of 78% to 88%, while refs. [17–24] studied skyscrapers, noting common design features and a correlation between height and efficiency. The authors of ref. [25] developed a model for tall office buildings, highlighting design's influence on efficiency, favoring conical layouts. The authors of ref. [26] assessed residential space use in Afghanistan, ref. [27] analyzed smart tech's impact on urban homes, suggesting substantial improvements, and ref. [28] noted land use benefits of corner positioning in Sudanese homes. The author of ref. [29] looked into hotel space efficiency, ref. [30] explored core structures in towers, ref. [31] introduced stakeholder analysis for planning, and ref. [32] proposed digitalization's impact on construction phases. The authors of ref. [33] studied lease span and corners in high-rises, ref. [34] enhanced solar absorption without sacrificing efficiency, and ref. [35] investigated load-bearing systems in offices. The authors of ref. [36] analyzed costs versus optimization in high-rise offices, revealing efficiency's impact on comfort benchmarks, while ref. [37] evaluated multi-use tower efficiency, advocating for optimal design integration. As seen in the literature survey above, the existing academic research insufficiently delves into the intricate examination of spatial effectiveness within tall hotel developments, a distinctive subset of tall buildings. This article fills this notable gap in knowledge.

Our research, based on data from 31 case studies, evaluates space efficiency by investigating pivotal design parameters in modern tall hotel buildings. This paper explores the effects of different design constraints on space efficiency, focusing on three critical components: 1. Key architectural considerations, encompassing service core design and form. 2. Key structural considerations, involving the choice of structural material and system. 3. Space efficiency and its interrelations with previously stated considerations. Through this analysis, this article aims to offer insights that can guide future design choices for hotel towers. By identifying trends and best practices, this research intends to inform more efficient architectural and structural design strategies for contemporary hotel towers.

This study, despite excluding the analysis of building performance concerning climate change and sustainable design, particularly in terms of embodied carbon in building materials and energy in use due to data constraints, underscores the critical importance of space efficiency in tall hotel buildings. Our focus highlights its significant impact on improving financial returns, enhancing occupant well-being, and promoting environmental sustainability within vertical urban landscapes.

The subsequent sections proceeded as follows: First, this study's research methodology was described, detailing the approach taken to gather and analyze data. Next, an examination of 31 case studies of hotel towers was presented, providing understanding for key factors impacting space efficiency. This section was followed by a thorough discussion, where the findings were explored in depth, highlighting trends, challenges, opportunities within the context of hotel design, and suggestions for future research directions. Finally, our study concluded with a summary of the key takeaways, offering recommendations for industry practitioners.

2. Research Methods

The case study method was used to systematically classify and compile data from 31 modern tall hotels, as detailed in Figure 1. This approach is frequently utilized in research to record qualitative and quantitative data, as well as to conduct a comprehensive literature review [38–40]. It facilitates a deep analysis of the architectural and structural characteristics of these projects, allowing for a detailed investigation of real-world examples. The case study approach offers an in-depth analysis of individual cases, providing researchers with valuable comprehensions into the unique planning elements and structural aspects of each design. By concentrating on specific examples, researchers can identify commonalities and differences across the spectrum of contemporary tall hotel designs, thus recognizing emerging patterns and trends. The flexibility inherent in this method permits the use of various data sources, including blueprints, schematics, and other relevant documents, to create a comprehensive understanding.

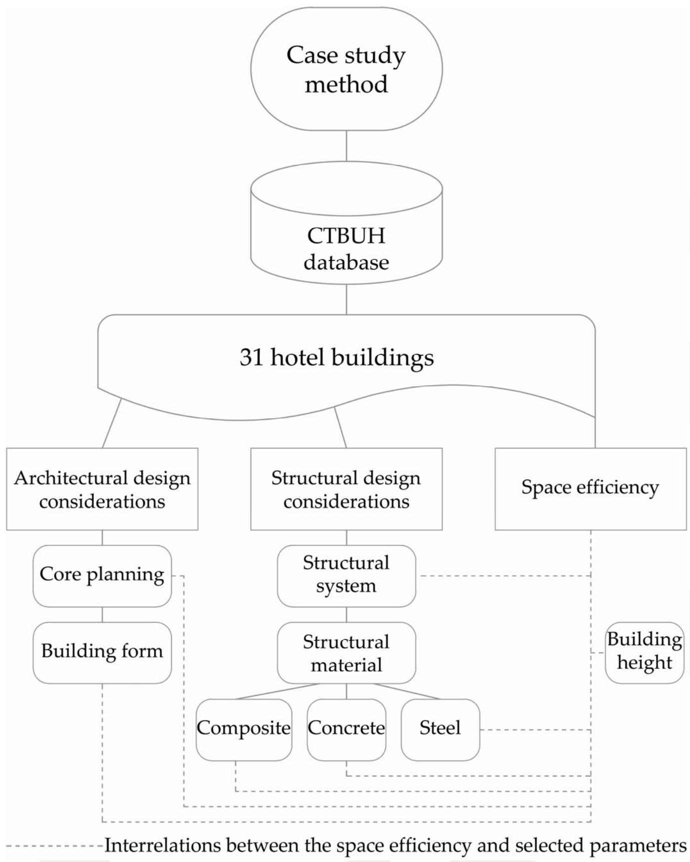


Figure 1. Research method flowchart (created by authors).

The analyzed 31 cases were either completed or under construction. In accordance with the classification by CTBUH (Council on Tall Buildings and Urban Habitat), buildings reaching a minimum of 14 floors or 50 m in height can be designated as "tall buildings" [41]. Our study sample selection criteria adhered to this specified definition. CTBUH is a leading nonprofit dedicated to advancing global urban development discussions, focusing on sustainable, resilient cities amidst urbanization and climate change. It determines tall building heights and awards titles like "The World's Tallest Building". Through initiatives like "Buildings of Distinction", it recognizes notable projects. CTBUH facilitates information exchange and networking for urban development professionals worldwide.

It is worth noting that the selection of 31 cases in this study ensures robust and representative results. When focusing on contemporary tall hotel buildings, the number of available and accessible cases is naturally limited. However, this sample size is sufficient to identify significant trends and patterns in spatial utilization and architectural features, since the diversity of the selected cases encompass a wide range of geographical locations, building heights, and design typologies, which enhances the generalizability of the findings. The examined hotels included eight each from the United States and China, three from Australia, two from the Netherlands, and one each from Canada, Panama, Chile, Brazil, Spain, Finland, the UAE, Japan, Taiwan, and Singapore, as depicted in Figure 2 and detailed in Appendix A. By covering various scenarios and contexts, this study captures a comprehensive view of current practices in tall hotel construction. Methodological precedents indicate that a sample size of around 30 cases is often adequate for deriving meaningful conclusions, providing a balance between the depth and breadth of analysis, as demonstrated by previous studies [18,22,24]. Thus, the chosen 31 cases form a solid foundation for understanding spatial utilization within tall hotel buildings, ensuring that this study's insights are both reliable and widely applicable. This comprehensive approach enables the identification of recurring themes, such as core typology, building forms, structural systems, and material.

Figure 2. Tall hotel cases across various nations depicted geographically on a global map (created by authors).

Like office [17], residential [18], and mixed-use towers [19], the planning of hotel towers is driven by architectural and structural requirements. These essential considerations encompass the following:

- Core planning, influencing vertical circulation and the distribution of shafts;
- Form, dictating the size and floor slab layouts;
- Structural system, determining the size and placement of structural elements;
- Structural material, impacting the size of load-bearing elements.

The core types recommended by [19] are selected for implementation because of its comprehensive structure, which involves four key types: central, atrium, external, and peripheral. Additionally, forms are classified into six categories: prismatic, setback, tapered, twisted, tilted, and free, as seen in Appendix B.

Choosing the proper structural system is crucial for maximizing space utilization in tall hotel constructions, as it directly impacts the organization and size of structural components. This paper adopts a more extensive classification proposed by [17] for tall buildings, which includes the following: (1) rigid frame; (2) shear frame; (3) mega core; (4) mega column; (5) outriggered frame; (6) tube; and (7) buttressed core systems.

The selection of structural materials is a critical parameter having an impact on space efficiency. These materials typically fall into three classifications: steel, (reinforced) concrete, and composite. In this article, focusing on vertical load-bearing elements such as shear walls and columns as the main load-bearing components, "composite" was employed to describe buildings wherein load-bearing members comprise a combination of concrete, steel, or both.

Space efficiency is termed as the effective utilization of net floor area (NFA) relative to GFA. This feature carries considerable prominence, as it involves increasing the use of floor areas to generate optimal financial returns. The level of spatial efficiency largely depends on many factors, counting the choice of structural frameworks and architectural design, as detailed in Appendix C.

In our research, the assessment of space efficiency was executed by computing the proportion of NFA to GFA, providing a numeric gauge of how efficiently the space is utilized. Simultaneously, the calculation of the core area relative to the GFA involved determining the percentage of the service core to the GFA, giving insights into the share of space assigned to essential structural and service components within the building's total area.

Spatial efficiency calculation involves two main ratios: NFA to GFA and core to GFA. The NFA is obtained by subtracting the service core area from the GFA, isolating functional spaces dedicated to activities, excluding infrastructure and support services areas. The NFA-to-GFA ratio quantifies how efficiently floor area is exploited for practical purposes, emphasizing the efficiency of space distribution.

The core-to-GFA ratio is a key metric in spatial efficiency calculations. It measures the percentage of GFA taken up by the service core, which includes essential facilities like elevators, stairwells, utility rooms, and other central services. This ratio offers valuable insights into how much of the building's floor space is dedicated to infrastructure, affecting the overall efficiency of space utilization.

3. Results and Discussion

In this section, we delineate the essential components of architectural design, including core design and form, crucial structural considerations about systems and material, and space efficiency, as well as its interaction with diverse design factors.

3.1. Key Architectural Considerations: Core Planning and Form

Figure 3 illustrates that in 31 instances, the central core was predominantly employed, at 65%. This preference for the central core could be ascribed to its compacted nature, pivotal role within the structural framework, potential to enhance flexibility in façade arrangement, and contribution to fire safety, which collectively render it the most viable choice among core arrangements [42,43]. Furthermore, the absence of an external core and the less use of peripheral core typologies may be linked to their less favorable attributes, including longer fire escape distances and less efficient circulation routes [44]. Moreover, the absence of an atrium core arrangement may correlate with an increased need for heightened fire safety measures [45].

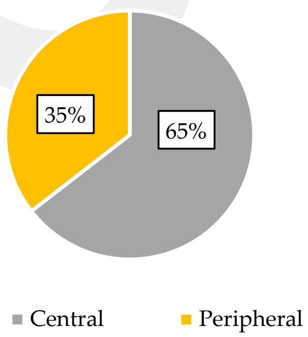


Figure 3. Case studies by core planning.

Prismatic towers emerged as the prevalent preference, accounting for 77% of the cases. On the other hand, the free type comprised 23%, as demonstrated in Figure 4.

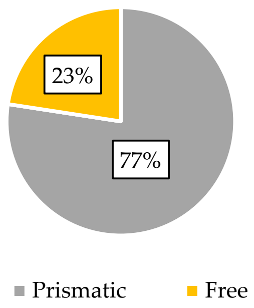


Figure 4. Case studies by form.

Prismatic forms in hotel construction offer a versatile and efficient approach [16] that combines structural robustness, aesthetic flexibility, and environmental sustainability. Their geometric simplicity facilitates optimized load distribution, enabling a more straightforward and cost-effective structural design while also supporting modular construction techniques that speed up the building process. The flat surfaces of prismatic structures allow for a variety of façade treatments, promoting a modern aesthetic that can be customized to reflect a hotel's unique branding. This design efficiency also enhances space utilization, maximizing capacity and guest comfort. Environmentally, prismatic forms contribute to sustainability by reducing material waste during construction and facilitating energy-efficient features like optimal insulation, daylighting, and natural ventilation. These benefits may have made prismatic forms an attractive choice for hotel projects, combining practicality with an eye-catching contemporary style.

3.2. Key Structural Considerations: System and Material

Concrete emerged as the predominant structural material, comprising over 80% of usage in the construction of hotel buildings, as highlighted in Figure 5. Several factors may have contributed to this dominance [46–48]: firstly, its cost-competitiveness across various countries, rendering it economically advantageous for large-scale projects; secondly, its inherent ease of use in both construction and manufacturing processes, facilitating efficient implementation on site; thirdly, its intrinsic fire-resistant properties, ensuring enhanced safety standards in high-rise structures; and finally, its exceptional ability to reduce the sway caused by wind in buildings surpasses that of steel alternatives, thereby enhancing structural stability and occupant comfort. This overwhelming adoption of reinforced concrete underscores its versatility and suitability for addressing the demanding requirements of tall hotel construction.

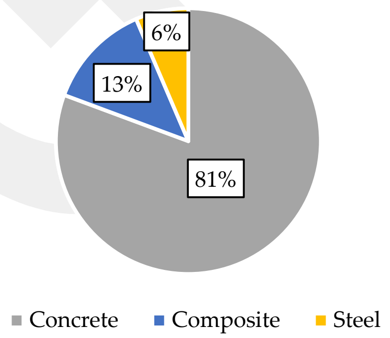


Figure 5. Case studies by structural material.

Due to various compelling reasons such as adherence to safety standards, economic concerns, and resistance to natural disasters, the use of concrete was predominant in tall hotel projects from different geographical regions such as the Far East, North America, and Australia.

1. Safety Standards
Far East

- Earthquake-Resistant Design [49–51]: Concrete structures are designed to withstand significant seismic forces due to their ability to flex and absorb energy without catastrophic failure. Advanced building codes in these regions, such as Chinese Code for Seismic Design of Buildings, mandate the use of materials and construction techniques that ensure buildings can endure earthquakes.
- Fire Resistance [52–54]: Concrete offers excellent fire resistance compared to steel. In densely populated areas, the ability to contain and prevent the spread of fire is crucial.

North America

- Wind and Earthquake Codes [55–57]: In the United States, especially in states like California (earthquakes) and Florida (hurricanes), building codes such as the International Building Code (IBC) incorporate stringent requirements for wind and seismic resistance. Concrete buildings perform well under these conditions due to their mass and rigidity.
- Progressive Collapse Prevention [58]: Post-9/11, there is an increased focus on designing buildings to prevent progressive collapse. Concrete structures can be designed with redundancies and robustness that help prevent such catastrophic failures.

Australia

- Cyclone Resistance [59]: Northern Australia is prone to cyclones, and concrete buildings provide the necessary strength and durability to withstand high winds and flying debris.
- Adaptation to Local Conditions [60]: Australian building codes, like the National Construction Code (NCC), emphasize durability and sustainability, areas where concrete excels.

2. Economic Considerations [61]
Cost and Availability of Materials

- Local Material Availability: In many regions, the raw materials for concrete—cement, aggregates, and steel—are locally available, making concrete construction economically viable.
- Cost Efficiency: Although the initial cost of concrete structures can be high due to the need for formwork and reinforcement, the long-term benefits such as low maintenance costs and durability often result in a lower total cost of ownership.

Labor Market

- Skilled Workforce: There is a well-established workforce skilled in concrete construction in these regions. The availability of trained labor ensures that construction projects can be completed efficiently and to high standards.

3. Natural Disaster Resilience [62]
Earthquakes

- Ductility and Energy Absorption: Concrete structures are designed to absorb and dissipate energy, which is crucial in earthquake-prone areas. The steel reinforcement provides tensile strength, while the concrete offers compressive strength.
- Post-Earthquake Usability: Concrete buildings often remain functional after an earthquake, which is critical for hotels that need to continue operations and provide shelter.

Hurricanes and Cyclones

- Wind Resistance: The mass and rigidity of concrete buildings provide resistance to high wind forces. The ability to design complex shapes and integrate shear walls contributes to their stability.
- Impact Resistance: Concrete structures can withstand the impact of debris carried by strong winds, minimizing structural damage and ensuring safety for occupants.

Floods and Tsunamis

- Structural Integrity: In flood-prone areas, the strength and durability of concrete structures help maintain integrity against water forces. Properly designed concrete buildings can resist the hydrodynamic and hydrostatic pressures associated with flooding.
- Corrosion Resistance: Advances in concrete technology, such as the use of corrosion-resistant reinforcements and admixtures, enhance the durability of concrete structures in coastal and flood-prone areas.

Consequently, the preference for reinforced concrete in high-rise hotel buildings across the Far East, North America, and Australia can be attributed to a combination of safety, economic, and environmental factors. Concrete structures offer unparalleled resilience against natural disasters such as earthquakes, hurricanes, and floods, aligning with stringent safety standards and economic considerations. Moreover, the availability of materials and skilled labor, combined with advancements in construction techniques, makes reinforced concrete the material of choice for ensuring the safety, durability, and cost-effectiveness of high-rise hotel buildings in these regions.

A shear-walled frame was the prevalent structural approach, encompassing over 70% of the structural composition across a comprehensive analysis of 31 cases, as delineated in Figure 6. In a shear-walled frame, the disadvantages of a rigid frame, when compared with a shear wall, and the restrictions of a shear wall, when compared with a rigid frame, are moderated when these members are combined [63–65]. In such systems, the frame provides additional support to the shear wall at higher levels, whereas the shear wall improves the stability of the frame at lower levels. Thus, these combined systems show enhanced resistance against horizontal loads, achieving greater rigidity than structures that employ solely a shear wall or a rigid frame system, as demonstrated in buildings like Westin Hotel and Oasia Hotel Downtown. This feature may explain why shear-walled frame systems are widely adopted.

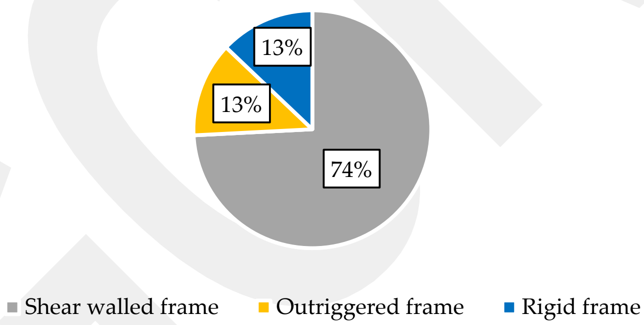


Figure 6. Case studies by structural system.

Similar to the widespread use of concrete, due to its superior structural performance, safety compliance, economic efficiency, and resilience to natural disasters, the use of the shear-walled frame system was predominant in tall hotel projects from different geographical regions such as the Far East, North America, and Australia [66–68]. Safety standards in various regions dictate the structural design of buildings, particularly the use of shear-walled frame systems due to their lateral stiffness and strength. In the Far East, especially China, these systems are crucial for seismic resilience as mandated by advanced codes like China's GB 50011-2010, which require buildings to endure significant seismic forces. North American codes, such as the IBC and NBCC, also emphasize seismic and wind resistance, with shear walls providing necessary rigidity and aiding in progressive collapse prevention post-9/11. In Australia, shear walls are vital for cyclone resistance, aligning with the National Construction Code's emphasis on structural integrity. Economically, shear-walled frame systems are cost-efficient due to the use of locally available concrete, reducing material costs and speeding up construction. They also offer long-term durability, minimizing maintenance expenses. These systems excel in natural disaster resilience by resisting lateral loads from earthquakes, dissipating seismic energy, and withstanding high winds and debris impacts from hurricanes and cyclones. Additionally, they maintain structural integrity during floods and tsunamis, with advances in concrete technology enhancing their durability in harsh environments. In consequence, the adoption of shear-walled frame systems in high-rise hotel buildings in the Far East, North America, and Australia is driven by a combination of stringent safety standards, economic efficiency, and resilience to natural disasters. Shear-walled frame systems provide the necessary lateral stiffness and strength to withstand seismic, wind, and flood forces, aligning with local building codes and safety regulations. Their cost-effectiveness, durability, and efficient construction make them an optimal choice for the hospitality industry, ensuring the safety and comfort of occupants while minimizing long-term operational costs.

3.3. Space Efficiency in Tall Hotel Buildings

In this paper, by analyzing 31 occurrences, we determined that the average space efficiency and the ratio of core area to GFA averaged 81.2% and 16%, respectively. The range varied from the lowest of 70% to 4% to the highest of 94% to 28%, as depicted in Appendix C.

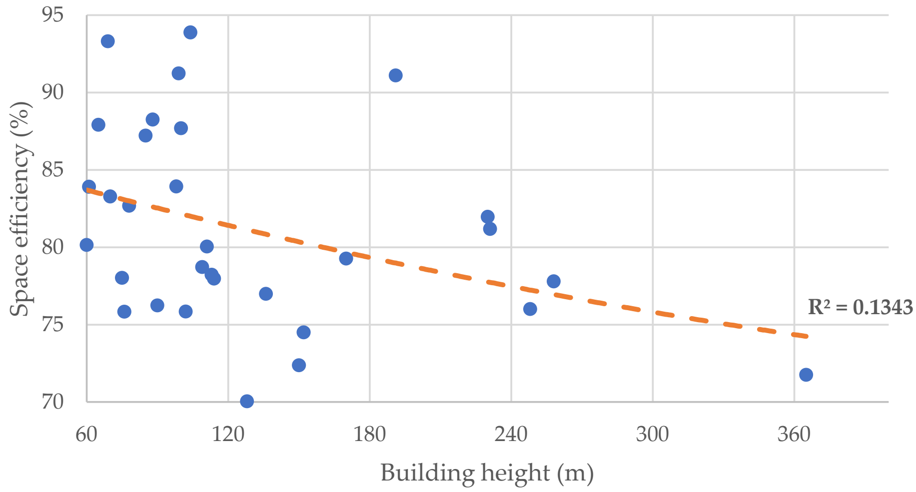
3.3.1. Interrelation of Space Efficiency and Building Height

Figure 7a,b show the interrelationship between the building height and its spatial efficiency. Each dot in the figure represents a hotel tower within the examined towers. A polynomial regression analysis was employed to establish relationships with these data points. The polynomial regression model offers several advantages over other models such as linear regression, especially when dealing with complex, non-linear relationships [69–71]. It provides flexibility to capture such relationships by fitting curves through the introduction of polynomial terms, resulting in a more accurate representation of data trends and often yielding lower residuals and higher R-squared values. This improved fit enhances the model's predictive power, allowing for better predictions beyond the sample data range. The ability to adjust the degree of the polynomial grants control over the model's complexity, facilitating a tailored fit to specific datasets. Additionally, polynomial regression can identify and model turning points and inflection points, which are crucial in various applications, and can incorporate interaction terms, allowing for the modeling of interactions between variables.

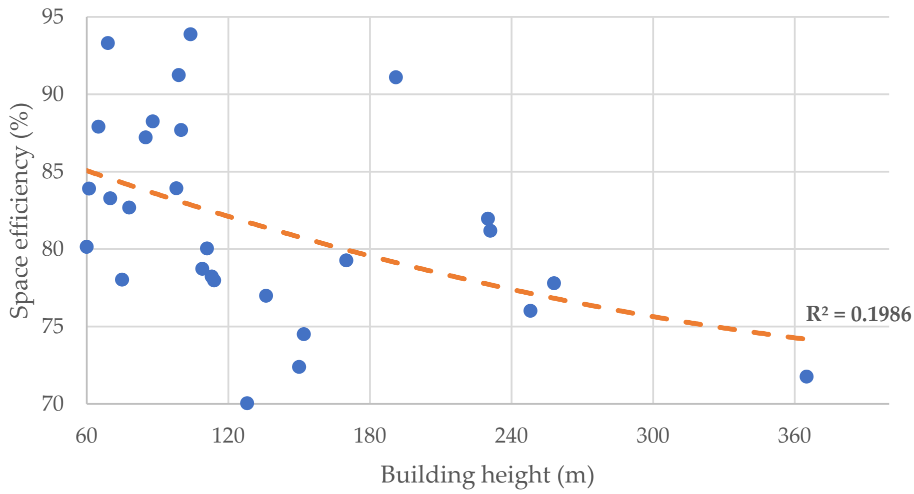
Notably, outliers within the dataset were identified, including J Hotel @ Jervois Street, towering at a height of 102 m with a 76% space efficiency ratio and a core-to-GFA ratio of 13%, Hotel Riu Plaza New York Times Square soaring at 90 m with a 76% space efficiency ratio and a core-to-GFA ratio of 19%, and Hôtel Monville towering at a height of 76 m with a 76% space efficiency ratio and a core-to-GFA ratio of 18%.

In Figure 7b, it is evident how the outliers impact the regression line. As illustrated in Figure 7a, there is a trend for space efficiency to decline. Upon the removal of the identified outliers, it becomes apparent that this downward trend extends across the entire trendline, as demonstrated in Figure 7b. This reduction can be rationalized by considering that higher structures face greater challenges in achieving optimal space efficiency owing to the increased size of core spaces and structural elements, a notion underscored in studies [16–18].

Additionally, Figure 8a,b offer further insight into the correlation between the height and the percentage of core over GFA, serving as a measure of the spatial demands associated with taller structures. It becomes evident that as the height of the building rises, there is a notable escalation in the necessity for a larger core area. This trend is highlighted in Figure 8b, where the removal of outliers showcases a consistent rise in the core area requirement along the entire spectrum of building heights, mirroring the observations made in Figure 7b. This phenomenon underscores the inherent challenges in achieving optimal spatial efficiency in taller buildings, as the increased size of the structure necessitates greater core space and load-bearing components, as elucidated in previous research [16–18].

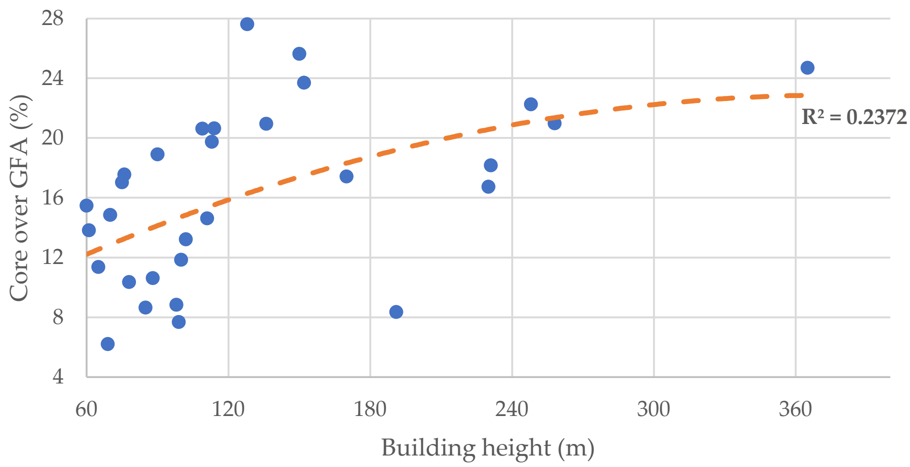


(**a**)



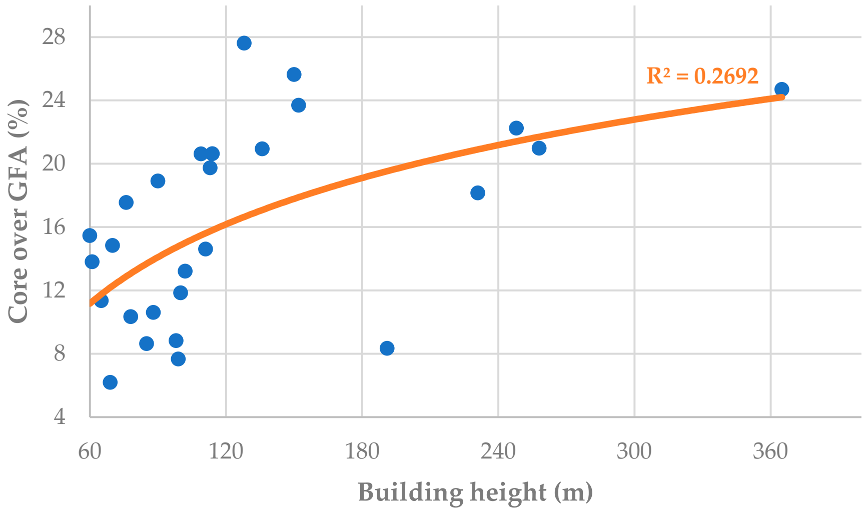
(**b**)

Figure 7. The correlation between the height and its space efficiency, showcasing two scenarios: (**a**) incorporating outliers and (**b**) with outliers excluded.



(**a**)

Figure 8. *Cont.*



(**b**)

Figure 8. The association between the ratio of the core over GFA and the height, presented in two scenarios: (**a**) incorporating outliers and (**b**) with outliers excluded.

3.3.2. Interrelationship of Space Efficiency and Core Planning

Figure 9 indicates the correlation between spatial efficiency and core type. The graph displays bars on the right side, indicating the total number of hotels grouped by their core typology. Also, orange dots are used to designate the spatial efficiency of these configurations for each corresponding core arrangement. Additionally, a gray bar is incorporated into the graph to illustrate the frequency of hotels sharing the same core arrangement.

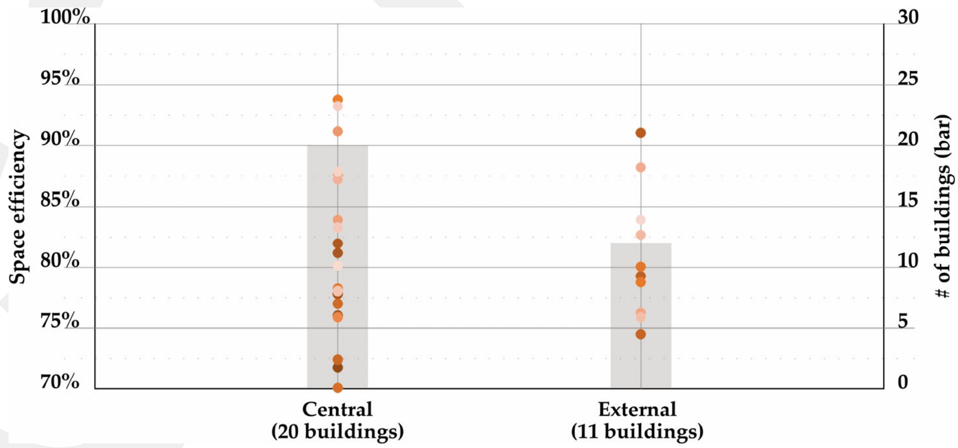


Figure 9. Interrelation between space efficiency and core planning.

The central type was the prevalent preference, with 20 buildings employing this configuration. These examples displayed spatial efficiency levels ranging from 70% to 94%, with an average of 81%. On the contrary, investigations involving the peripheral core, numbering 11, showed spatial efficiency varying from 74% to 91%, with an average of 81% as well. Thus, there is no disparity in the average spatial efficiency among different core forms.

3.3.3. Interrelationship of Space Efficiency and Building Form

Figure 10 exhibits the interrelationship between spatial efficiency and the forms of structures. The diagram features bars on the right side, revealing the total count of buildings classified by their respective forms. Additionally, blue dots are used to illustrate spatial efficiency of these structures in the case study, corresponding to each specific form. Furthermore, a gray bar is used to show the frequency of edifices sharing the same form under examination.

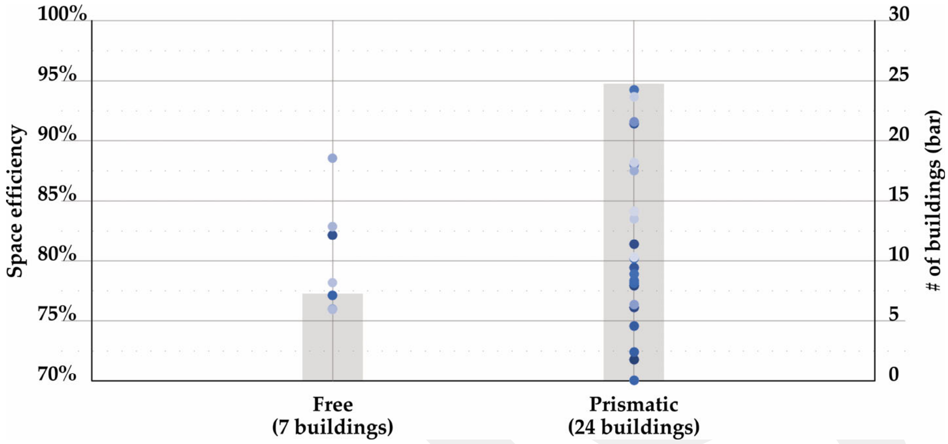


Figure 10. Interrelation between space efficiency and building form.

Prismatic forms appeared as the primary selection, detected in 24 hotels. These types demonstrated spatial efficiency ratios across from 70% to 94%, with an average of 82, while cases with free forms are limited, totaling 7 cases.

3.3.4. Interrelationship of Space Efficiency and Structural System

Figure 11 reports the relationship between spatial efficiency and load-bearing systems. The illustration reveals bars on the right side, representing the total count of cases classified by their structural systems. Also, orange dots are used to show the spatial efficiency of these edifices corresponding to each specific structural system. Furthermore, a gray bar is to denote the occurrence of cases sharing the same structural systems.

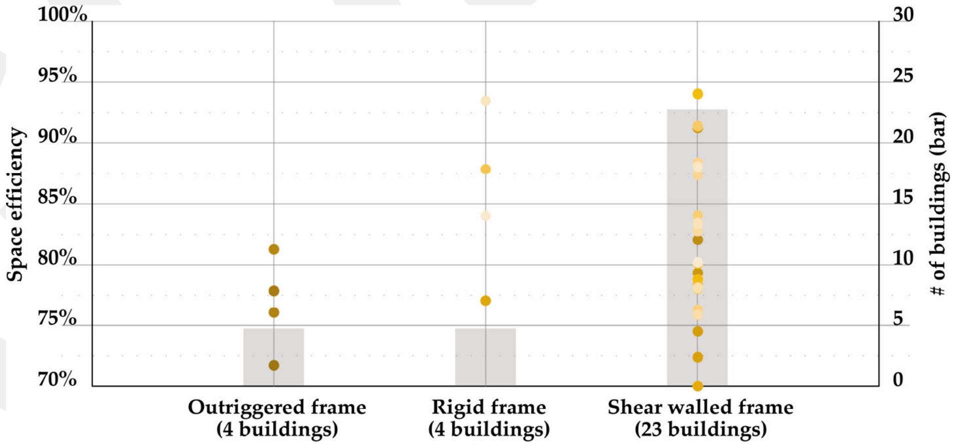


Figure 11. Interrelation between space efficiency and structural system.

In our investigation into hotels, the shear-walled frame has surfaced as the prevailing structural system, evident in 23 occurrences. These configurations have demonstrated space efficiency levels ranging from 70% to 94%, averaging 81%. Conversely, structures employing outriggered frames and rigid frames, comprising four instances each, have exhibited an average space efficiency of 77% and 85%, respectively.

3.3.5. Interrelationship of Space Efficiency and Structural Material

Figure 12 depicts the correlation between spatial efficiency and structural materials. The diagram has bars on the right-hand side, indicating the total count of cases categorized by their respective structural materials. Additionally, green dots are used to designate the spatial efficiency of these configurations for each specific structural material. Also, a gray bar illustrates the occurrence of hotels that share the same structural material.

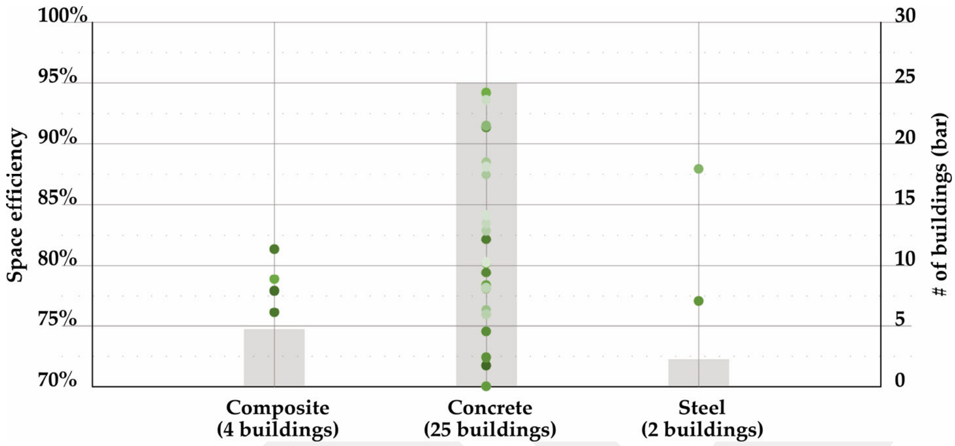


Figure 12. Interrelation between space efficiency and structural material.

In tall hotel towers, the predominant structural materials utilized encompass concrete. The spatial efficiency levels for these materials were noted to span from 70% to 94%, with a mean efficiency of 82%.

Overall, our study aims to gather and combine data from 31 tall hotel buildings. The primary objective is to examine spatial efficiency concerning both architectural and structural design features of hotels, aiming to deepen our understanding of planning and constructing such edifices. Our findings reveal parallels and differences in relation to prior studies (e.g., [17]), as follows:

The central core was the primary preference for core design in modern high-rise architecture [17–25]. This trend is notably prevalent across a diverse array of mid-rise and tall towers, which serve various functions and exhibit different architectural forms. This architectural design choice is observed in numerous geographical locations, highlighting the central core's versatility and efficacy in accommodating different structural and aesthetic requirements. The preference for central cores in hotel building design may stem from their multifaceted advantages. Firstly, central cores enable a greater concentration of residential units along the edges, enhancing the availability of natural light and expansive vistas for inhabitants. This arrangement not only improves the quality of inhabiting spaces but also contributes to the overall aesthetic appeal of the structure. Moreover, central cores play a pivotal role in ensuring fire safety compliance by facilitating safer evacuation procedures. With units situated in close proximity to the core, evacuation routes are streamlined, reducing the risk and potential chaos during emergencies. This feature is particularly crucial in high-rise and mid-rise structures where efficient evacuation is paramount. Additionally, the architectural versatility offered by central cores is significant; contrasting exterior core types, they seamlessly integrate with the design without compromising its external appearance. This adaptability allows architects to explore various design possibilities while maintaining structural integrity and safety standards, further cementing the widespread adoption of central core configurations in modern building projects.

Drawing from extensive research on various types of tall buildings including residential towers [18], Middle Eastern supertall structures [22], and prismatic skyscrapers [24], it becomes evident that reinforced concrete stands out as the primary material of choice in the construction of hotel towers. This preference is underscored by several factors contributing to its widespread adoption. Firstly, reinforced concrete enjoys a competitive pricing advantage in construction markets across diverse regions, making it an economically viable option for developers and builders alike. Additionally, its versatility and ease of use in building processes make it a viable choice for erecting tall structures efficiently. Moreover, reinforced concrete's inherent fire resistance features add a layer of safety and security, particularly crucial in high-rise buildings where fire hazards pose significant risks. These combined attributes position reinforced concrete as the material of choice for hotel towers seeking to balance cost-effectiveness, practicality, and safety in their construction endeavors. Furthermore, while office [17], residential [18], and mixed-use skyscrapers [19] often employ outriggered frame systems to optimize lateral stability and load distribution, tall hotel buildings more commonly incorporate shear-walled frame configurations. This variation in structural design mirrors distinct architectural practices and lateral load requirements. Outriggered frame systems enhance rigidity and manage loads effectively in supertall buildings, while shear-walled frame systems provide robust lateral force resistance, addressing the unique seismic and wind forces, and structural needs prevalent in regions where hotels are predominantly built.

A proposed standard for spatial utilization within tall buildings targets an ambitious 75% utilization rate [72]. Comprehensive research on skyscrapers—encompassing office [17], residential [18], and mixed-use buildings [19], yet excluding those constructed with timber—reveals a spectrum of spatial efficiency, with mean utilization rates spanning from 71% to 76%. The core area-to-GFA ratio in these studies typically fluctuates between 19% and 26%, with documented extremes for both spatial efficiency and the core area-to-GFA ratio within this range. These findings highlight the variability and potential for optimization in skyscraper design, underscoring the importance of context-specific strategies to enhance spatial utilization and efficiency in high-rise developments.

In examining various types of buildings, notable differences in space efficiency and core area-to-GFA ratios were observed. Office skyscrapers [17], for instance, demonstrated a broad range of space efficiencies from 63% to 82%, with core area-to-GFA ratios varying between 15% and 36%. Residential [18] and multi-use skyscrapers [19] exhibited similar variations in their spatial metrics. Contrastingly, a study of 55 Finnish mid-rise timber apartments revealed higher space efficiency, ranging from 78% to 88%, with an average of 83% [16]. Our article presents an analysis of 31 cases, showing an average space efficiency of 81.2% and an average core area-to-GFA ratio of 16%. The measured values spanned from a minimum of 70% and 4% to a maximum of 94% and 28%, respectively. These findings highlight the diversity in spatial efficiency and core area utilization across different building types and underscore the importance of tailored architectural and engineering approaches to optimize space usage.

The findings from this paper underscore several critical lessons for the architectural and engineering communities: (i) Design Optimization: The prevalence of prismatic forms and central core typologies highlights their effectiveness in maximizing spatial efficiency within tall hotel buildings. Architects and engineers can leverage these findings to optimize building designs for similar projects, enhancing both functionality and economic viability. (ii) Material Selection and Structural Systems: The preference for concrete and shear-walled frame systems suggests a robust choice for structural integrity and construction efficiency in hotel developments. This knowledge can guide future projects towards selecting appropriate materials and systems that balance performance with cost-effectiveness. (iii) Height Considerations: The inverse relationship between space efficiency and building height underscores the importance of careful planning and design adaptation as buildings increase in scale. This insight is crucial for managing spatial constraints effectively in taller structures. Looking ahead, these lessons are poised to influence future architectural and structural practices, promoting advancements in building efficiency, sustainability, and resilience within the hospitality sector. By disseminating these findings, this study aims to catalyze informed decision-making among stakeholders involved in hotel development projects.

Our study represents a foundational step towards understanding spatial utilization in tall hotel buildings, focusing on architectural and structural planning factors. Future research should expand on several fronts to deepen our understanding and enhance practical applications in hotel construction: (i) Advanced Structural Systems: Investigate innovative structural systems beyond shear-walled frames, exploring potential alternatives such as diagrids or hybrid systems that could potentially enhance both spatial efficiency and structural performance. (ii) Sustainability and Energy Efficiency: Extend the investigation to include a comprehensive analysis of sustainability metrics and energy efficiency strategies in tall hotel constructions. This could involve assessing the impact of building orientation, facade design, and renewable energy integration on overall spatial utilization and operational efficiency. (iii) Digital and Computational Tools: Utilize advanced computational modeling techniques and simulation tools to optimize spatial layouts in tall buildings. This includes leveraging data-driven approaches to predict and optimize spatial efficiency during the early design phases. By addressing these avenues, future research can provide a more nuanced understanding of spatial utilization in tall hotel buildings, offering practical insights that contribute to sustainable, efficient, and economically viable construction practices.

Other potential future research directions aimed at enhancing space efficiency in tall hotel buildings may include the following:

(a) Integration of artificial intelligence (AI) and machine learning [73]: investigating the application of AI algorithms for predictive space management, optimizing room layouts, and personalized guest experiences and exploring machine learning techniques to analyze guest preferences and behaviors, facilitating adaptive spatial configurations and service customization.
(b) Sustainable space solutions [74]: exploring sustainable design principles for tall hotel buildings, emphasizing space-efficient strategies that minimize environmental impact and assessing the feasibility of incorporating green technologies, such as vertical gardens, solar panels, and rainwater harvesting systems, into spatial design to enhance efficiency and sustainability.
(c) Modular and flexible design approaches [75]: investigating modular construction techniques for tall hotel buildings to enable the rapid assembly and reconfiguration of space according to changing demands and exploring flexible room layouts and multifunctional spaces that can adapt to varying occupancy rates and guest needs, maximizing space utilization throughout the building's lifecycle.
(d) Virtual reality (VR) and augmented reality (AR) applications [76]: exploring VR and AR technologies for virtual space planning, allowing designers and stakeholders to visualize and optimize spatial layouts before construction, and investigating immersive guest experiences through VR and AR applications, offering interactive room tours and personalized amenity selection to enhance guest engagement and satisfaction.
(e) Data-driven space optimization [77]: utilizing data analytics and sensor technologies to gather real-time occupancy data and feedback, enabling dynamic space optimization and resource allocation, and investigating the integration of IoT devices and smart building systems to automate space management processes and improve operational efficiency.
(f) Human-centric design principles [78]: exploring human-centered design principles to create spaces that prioritize guest comfort, well-being, and convenience and conducting research on ergonomic furniture, intuitive wayfinding systems, and sensory design elements to enhance the overall guest experience and satisfaction.

We recognize the importance of rigorously outlining the limitations encountered during our research and their implications for future investigations. In our study, several key limitations have been identified, each of which bears significance for shaping subsequent research directions. Firstly, our sample size, comprising 31 cases, was adequate for identifying significant trends within the scope of our study. Nonetheless, the somewhat limited size of our study may restrict the applicability of our findings to a wider range of hotel structures. To address this issue, future research efforts could greatly enhance their validity by utilizing larger and more diverse datasets that encompass low-rise hotel developments. This strategy would not only bolster the statistical reliability of our findings but also enable their broader applicability and validation across a variety of architectural settings. Secondly, our study was constrained by the availability and accessibility of data pertaining to contemporary tall hotel buildings. We relied predominantly on publicly accessible data sources and case studies, which may not comprehensively encompass all pertinent variables or the latest advancements in hotel construction technologies. Enhancing access to more comprehensive and up-to-date datasets would undoubtedly bolster the methodological soundness and reliability of future investigations in this field. Thirdly, our analysis predominantly focused on spatial utilization and architectural features, with limited exploration into the economic and environmental impacts associated with different design choices. To offer a more holistic understanding of tall hotel building designs, future research endeavors should incorporate in-depth examinations of these multifaceted dimensions. By delving deeper into the economic implications and environmental sustainability considerations of various design approaches, subsequent studies can provide nuanced insights that inform more informed decision-making processes within the industry.

4. Conclusions

Our study centers on space efficiency within tall hotel developments, filling a void in the current body of literature. Through a comprehensive examination of 31 buildings via literature reviews and case studies, this study investigates critical issues such as height, core types, forms, and structural materials and systems. The application of these findings in tall hotel towers incorporates various key considerations. The central core emerged as a prevalent architectural strategy, aiding designers in creating layouts that optimize space and accessibility while mitigating building challenges. Prismatic shapes, combined with shear-walled frame systems, emerged as the favored choice for load-bearing structures, fostering structural stability and space efficiency. The frequent utilization of reinforced concrete underscores a construction material approach aimed at harmonizing construction ease and speed with durability. With an average space efficiency hovering around 81% and a core area-to-GFA percentage of 16%, these benchmarks help building designers maximize rentable space and create effective hotel plans. In the design of tall hotel projects, the architectural designer's role is crucial as achieving high space efficiency becomes increasingly challenging with height due to the growing service core dimensions. This necessitates that architects lead the coordination of diverse proficiencies across various specialized disciplines and maintain a robust flow of information for all details involved.

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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. Tall Hotel Buildings

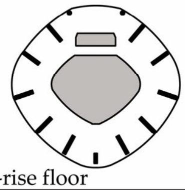
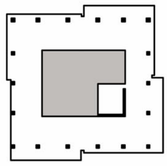
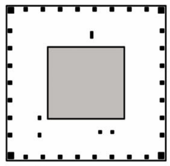
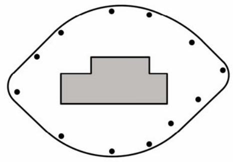
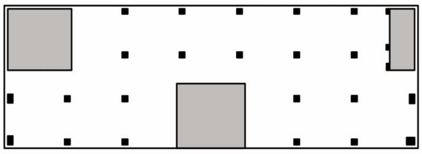
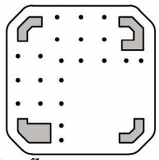
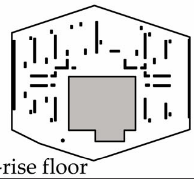
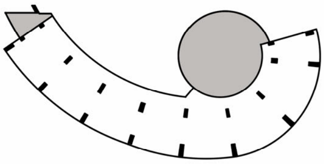
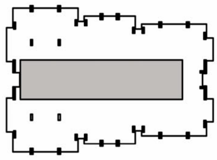
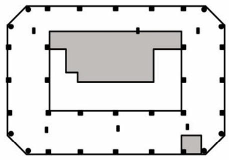
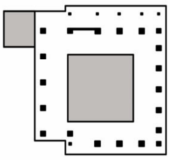
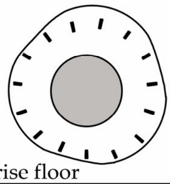
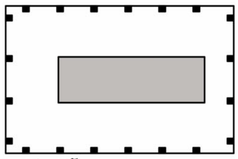
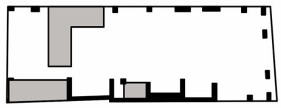
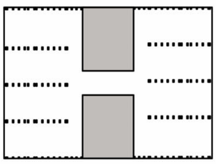
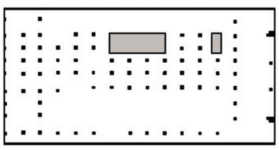
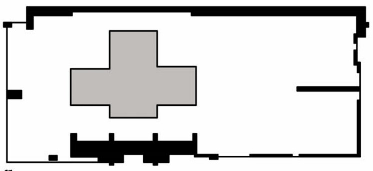
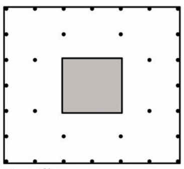
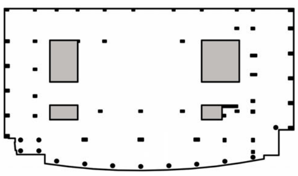
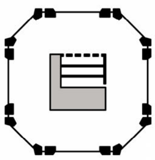
#	Hotel-Building Name	Country	City	Height (Meters)	# of Stories	Completion Date
1	Ciel Tower	UAE	Dubai	365	81	UC
2	Grand Parkray Hangzhou Hotel Tower 1	China	Hangzhou	258	50	2013
3	Yunda Central Plaza–St. Regis Hotel	China	Changsha	248	63	2016
4	Shangri-La by the Gardens	Australia	Melbourne	231	59	2023
5	Westin Hotel	China	Changsha	230	46	2018
6	Oasia Hotel Downtown	Singapore	Singapore	191	27	2016
7	Jewel Hotel	Australia	Gold Coast	170	48	2019
8	Hotel Las Americas Golden Tower	Panama	Panama City	152	31	2016
9	Bulgari Hotel	China	Shanghai	150	37	2017
10	APA Hotel & Resort Yokohama Bay Tower	Japan	Yokohama	136	37	2019
11	Kerry Hotel	China	Shanghai	128	30	2011
12	Hotel Porta Fira	Spain	L'Hospitalet de Llobregat	114	27	2010
13	Costanera Hotel	Chile	Santiago	113	28	2012
14	Moxy Hotel	USA	New York	111	30	2018
15	AC Hotel NoMad	USA	New York	109	26	OH
16	Hilton Hotel at 54th	USA	New York	104	34	2013
17	J Hotel @ Jervois Street	China	Hong Kong	102	29	2011
18	T30 Hotel	China	Changsha	100	30	2012
19	1 Hotel and Embassy Suites	USA	Nashville	99	26	2022
20	Next Hotel	Australia	Melbourne	98	27	2020
21	Hotel Riu Plaza New York Times Square	USA	New York	90	27	2016
22	Ramada Hotels and Suítes	Brazil	Recife	88	26	2015
23	CHAO Hotel	China	Beijing	85	25	2017
24	Clarion Hotel Helsinki	Finland	Helsinki	78	16	2016
25	Hôtel Monville	Canada	Montreal	76	20	2018
26	citizenM Hotel	USA	New York	75	19	2019
27	QO Hotel	Netherlands	Amsterdam	70	21	2017
28	Graduate Hotel	USA	New York	69	18	2021
29	Westin Hotel	USA	Austin	65	19	2015
30	Hotel Resonance Taipei	Taiwan	Taipei	61	16	2020
31	Fletcher Hotel Amsterdam	Netherlands	Amsterdam	60	17	2013

Appendix B. Tall Hotel Buildings by Building Form, Core Type, Structural System, and Structural Material

#	Hotel-Building Name	Building Form	Core Type	Structural System	Structural Material
1	Ciel Tower	Prismatic	Central	Outriggered frame	Concrete
2	Grand Parkray Hangzhou Hotel Tower 1	Free	Central	Outriggered frame	Composite
3	Yunda Central Plaza –St. Regis Hotel	Prismatic	Central	Outriggered frame	Composite
4	Shangri-La by the Gardens	Prismatic	Central	Outriggered frame	Composite
5	Westin Hotel	Prismatic	Peripheral	Shear walled frame	Concrete
6	Oasia Hotel Downtown	Prismatic	Peripheral	Shear walled frame	Concrete
7	Jewel Hotel	Free	Peripheral	Shear walled frame	Concrete
8	Hotel Las Americas Golden Tower	Prismatic	Peripheral	Shear walled frame	Concrete
9	Bulgari Hotel	Prismatic	Central	Shear walled frame	Concrete
10	APA Hotel & Resort Yokohama Bay Tower	Prismatic	Central	Rigid frame system	Steel
11	Kerry Hotel	Prismatic	Central	Shear walled frame	Concrete
12	Hotel Porta Fira	Free	Central	Shear walled frame	Concrete
13	Costanera Hotel	Prismatic	Central	Shear walled frame	Concrete
14	Moxy Hotel	Prismatic	Peripheral	Shear walled frame	Concrete
15	AC Hotel NoMad	Prismatic	Peripheral	Shear walled frame	Composite
16	Hilton Hotel at 54th	Setback	Central	Shear walled frame	Concrete
17	J Hotel @ Jervois Street	Prismatic	Central	Shear walled frame	Concrete
18	T30 Hotel	Prismatic	Central	Rigid frame system	Steel
19	1 Hotel and Embassy Suites	Prismatic	Central	Shear walled frame	Concrete
20	Next Hotel	Free	Central	Shear walled frame	Concrete
21	Hotel Riu Plaza New York Times Square	Prismatic	Peripheral	Shear walled frame	Concrete
22	Ramada Hotels and Suítes	Prismatic	Peripheral	Shear walled frame	Concrete
23	CHAO Hotel	Prismatic	Central	Shear walled frame	Concrete
24	Clarion Hotel Helsinki	Prismatic	Peripheral	Shear walled frame	Concrete
25	Hôtel Monville	Prismatic	Peripheral	Shear walled frame	Concrete
26	citizenM Hotel	Prismatic	Central	Shear walled frame	Concrete
27	QO Hotel	Free	Central	Shear walled frame	Concrete
28	Graduate Hotel	Free	Central	Rigid frame system	Concrete
29	Westin Hotel	Free	Central	Shear walled frame	Concrete
30	Hotel Resonance Taipei	Prismatic	Peripheral	Rigid frame system	Concrete
31	Fletcher Hotel Amsterdam	Prismatic	Central	Shear walled frame	Concrete

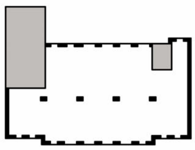
Appendix C. Space Efficiency and Core/GFA of Tall Hotel Buildings

#- Building Name
(Buildings are listed from highest to lowest.)
- 1 to 20

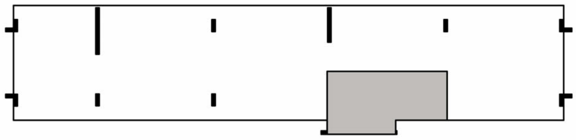
#- Building Name	Space Efficiency	Core/GFA	Low-rise floor
1-Ciel Tower	72%	25%	 Low-rise floor
2-Grand Parkray HangzhouHotel	78%	21%	 Low-rise floor
3-Yunda Central Plaza	76%	22%	 Low-rise floor
4-Shangri-La by the Gardens	81%	18%	 Low-rise floor
5-Westin Hotel	82%	17%	 Low-rise floor
6-Oasia Hotel Downtown	91%	8%	 Low-rise floor
7-Jewel Hotel	79%	17%	 Low-rise floor
8-Hotel Las Americas Golden Tower	74%	24%	 Low-rise floor
9-Bulgari Hotel	72%	26%	 Low-rise floor
10-APA Hotel	77%	21%	 Low-rise floor
11-Kerry Hotel	70%	28%	 Low-rise floor
12-Hotel Porta Fira	78%	21%	 Low-rise floor
13-Costanera Hotel	78%	20%	 Low-rise floor
14-Moxy Hotel	80%	15%	 Low-rise floor
15-AC Hotel NoMad	79%	21%	 Low-rise floor
16-Hilton Hotel at 54th	94%	4%	 Low-rise floor
17-J Hotel @ Jervois Street	76%	13%	 Low-rise floor
18-T30 Hotel	88%	12%	 Low-rise floor
19-1 Hotel and Embassy Suites	91%	8%	 Low-rise floor
20-Next Hotel	84%	9%	 Low-rise floor

#- Building Name (Buildings are listed from highest to lowest.)		**# - 21 to 31**
Building	**Space Efficiency**	**Core/GFA**
21-Hotel Riu Plaza	76%	19%
22-Ramada Hotels and Suítes	88%	11%
23-CHAO Hotel	87%	9%
24-Clarion Hotel Helsinki	83%	10%
25-Hôtel Monville	76%	18%
26-citizenM Hotel	78%	17%
27-QO Hotel	83%	15%
28-Graduate Hotel	93%	6%
29-Westin Hotel	88%	11%
30-Hotel Resonance Taipei	84%	14%
31-Fletcher Hotel Amsterdam	80%	15%

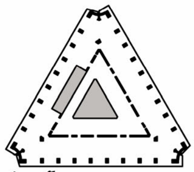
21-Hotel Riu Plaza:


Low-rise floor

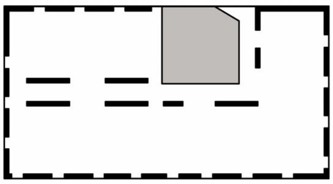
22-Ramada Hotels and Suítes:


Low-rise floor

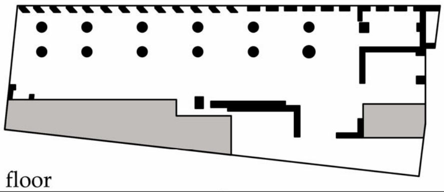
23-CHAO Hotel:


Low-rise floor

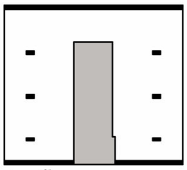
24-Clarion Hotel Helsinki:


Low-rise floor

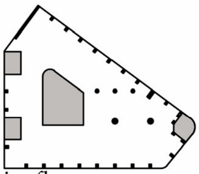
25-Hôtel Monville:


Ground floor

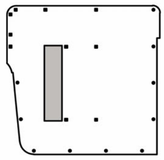
26-citizenM Hotel:


Low-rise floor

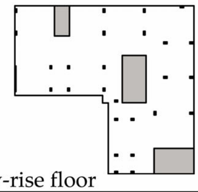
27-QO Hotel:


Low-rise floor

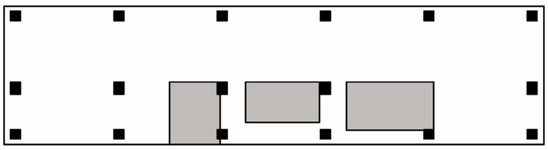
28-Graduate Hotel:


Low-rise floor

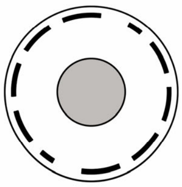
29-Westin Hotel:


Low-rise floor

30-Hotel Resonance Taipei:


Ground floor

31-Fletcher Hotel Amsterdam:


Low-rise floor

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