Article

A Comparative Analysis of Skyscraper Design Characteristics in the Middle East, Asia, and North America

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ABSTRACT

The proliferation of skyscrapers in rapidly urbanizing regions necessitates a comparative understanding of architectural and structural design strategies. The Middle East, Asia, and North America have emerged as dominant centers of high-rise development, each influenced by unique environmental, cultural, and economic conditions. This study employs a case study approach, analyzing 133 skyscrapers (≥300 m) using qualitative and quantitative metrics. The analysis focuses on core typology, structural systems, materials, and architectural form, based on data extracted from the Council on Tall Buildings and Urban Habitat (CTBUH) database. Findings reveal regional distinctions: Asian skyscrapers favor tapered and composite designs with outriggered frame systems; Middle Eastern towers emphasize prismatic forms using concrete; and North American high-rises balance setback and prismatic forms with concrete and shear-frame systems. A central core layout dominates all regions, driven by efficiency and safety considerations. These insights offer valuable benchmarks for architects, engineers, and urban planners aiming to optimize skyscraper design in dense urban contexts. These insights offer valuable benchmarks for architects, engineers, and urban planners aiming to optimize high-rise design in dense urban contexts.

KEYWORDS: skyscraper; design; comparison; Middle East; Asia; North America

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INTRODUCTION

Skyscrapers are iconic representations of architectural ambition, technological prowess, and urban identity, embodying the rapid transformation of urban landscapes around the world [1–3]. Over recent decades, regions such as the Middle East [4], Asia [5], and North America [6] have emerged as distinct centers for skyscraper development, each marked by unique architectural patterns and structural innovations shaped by economic, cultural, and environmental forces. This comparative study explores the design evolution of skyscrapers within these three regions, providing insight into how localized priorities and challenges influence high-rise construction in complex and densely populated urban environments.

In the Middle East, the recent surge in skyscraper construction is part of a broader regional strategy to establish global business and tourism hubs, fueled by economic diversification efforts in oil-rich nations and the desire to create internationally recognizable skylines [7]. Skyscrapers in Middle Eastern cities such as Dubai, Abu Dhabi, and Riyadh not only serve as functional buildings but also act as powerful symbols of national progress and modernization [8–10]. High-rise architecture has increasingly been understood as a tool for constructing urban identity and global visibility, particularly in rapidly developing regions [11]. These supertall structures often prioritize spatial efficiency, balancing high-density residential and commercial demands within relatively confined urban areas. Asia, particularly the rapidly growing urban centers in China, Japan, and South Korea, has become one of the world's most active skyscraper hubs, driven by rapid urbanization, population growth, and economic expansion [12–14]. In cities like Hong Kong, Shanghai, and Tokyo, the scarcity of available land has propelled a vertical building strategy that maximizes land use within increasingly dense metropolitan areas [15–17]. North America, as the birthplace of the modern skyscraper, has a long-standing tradition of high-rise development that dates back to the late 19th century [18]. Cities like New York and Chicago were early adopters of skyscraper construction, setting architectural and engineering standards that influenced global design practices [19,20]. North American skyscrapers reflect a legacy of structural innovation, from the steel-frame constructions of early 20th century towers to the glass-and-steel aesthetics of mid-century International Style buildings [21]. Today, North American high-rises are characterized by a focus on maximizing space efficiency, a necessity driven by high urban land values, especially in cities like New York, Los Angeles, and Chicago.

Over the past five years, significant advancements have reshaped not only the design, construction, and sustainability performance of supertall skyscrapers but also the way in which these buildings are conceived as integrated urban systems. In terms of design technology, the integration of Building Information Modelling (BIM) [22–24], parametric modelling, and computational fluid dynamics (CFD) simulations [25–27] has enabled highly precise structural optimization, façade performance tuning, and wind-load mitigation strategies, allowing architects and engineers to test multiple scenarios virtually before construction begins. These tools have also facilitated closer collaboration among multidisciplinary teams, reducing errors, optimizing material use, and accelerating delivery timelines. Sustainability-driven innovations have expanded beyond conventional energy efficiency measures to include high-performance façades with dynamic shading [28], double-skin envelope systems [29] for enhanced thermal regulation, on-site renewable energy integration such as building-integrated photovoltaics [30], and the use of engineered wood products [31–33] in hybrid high-rise structures to reduce embodied carbon. Regionally, Asia has led in adopting composite-structure prefabrication for rapid, high-density urban development [34], pairing technological innovation with mass-housing strategies in megacities; the Middle East has implemented advanced passive cooling and thermal control technologies suited to hot–arid climates, often integrated with iconic architectural expressions; and North America has emphasized structural retrofitting and adaptive reuse of high-rise buildings to meet stringent energy codes [35], thereby extending building lifespans and minimizing demolition-related emissions. Collectively, these developments illustrate a growing convergence of technological sophistication, climate-responsive design, and sustainability imperatives, positioning supertall skyscrapers as both architectural landmarks and active contributors to resilient, resource-efficient urban environments.

This study seeks to provide a comprehensive comparative analysis of skyscraper design patterns in the Middle East [36], Asia [37], and North America [38], focusing on critical design elements such as architectural form, structural system, and core typology. By examining these elements, the study aims to distinguish itself from textbook-level generalizations by offering statistically validated regional patterns that are often assumed but rarely demonstrated quantitatively in literature. This objective is achieved through a rigorous, data-driven examination of 133 supertall skyscrapers (≥300 m), classified and analyzed based on consistent typological indicators across regions.

The methodological innovation of this research lies in its integration of architectural and structural parameters into a single comparative framework. Unlike many existing works that focus exclusively on either structural efficiency or formal aesthetics, this study recognizes the interdependence of form, structure, and function in high-rise design. Rather than relying on anecdotal or stylistic interpretation, it presents a systematic assessment of regional patterns based on measurable indicators such as function (residential, office, mixed-use), core type (central, external, peripheral), formal geometry (prismatic, tapered, freeform, etc.), and structural systems (outriggered frame, diagrid, mega-frame, etc.). This cross-tabulation across disciplines allows for a more holistic understanding of skyscraper typologies and responds directly to calls in the literature for more integrated approaches [39–41].

In academic discussions, relatively few studies have concentrated on the integrated decision-making processes for both architectural and structural aspects of skyscrapers. Ali M, et al. 2007 [39] conducted a review of advancements in structural systems and supporting technologies pertinent to tall building design. Wood A, et al. 2008 [40] examined various patterns, key motivators, and obstacles in the design of tall buildings, focusing on aspects such as geographical location, height, function, and materials. Additionally, Elnimeiri M, et al. 2010 [41] explored the historical progression and evolving interaction between structural systems and architectural form in the context of high-rise towers. Moon KS, et al. 2012 [42] analyzed structural systems for tall edifices, focusing on their relative efficiency and optimal configurations. Alaghmandan M, et al. 2014 [43] examined architectural patterns and structural aspects by analyzing 73 supertall buildings. Ali M, et al. 2018 [44] later expanded upon their previous structural classification [40], incorporating new categories such as buttressed core, in response to emerging structural innovations in skyscraper design. Yusuf DA, et al. 2023 [45] studied architectural and structural design considerations of 93 supertall towers globally.

By grounding its analysis in empirical data and offering a multi-variable comparison across global regions, this study provides original insight into how high-rise architecture adapts to diverse urban, cultural, and economic contexts. Unlike generalized design guides or technical handbooks, it reveals how seemingly globalized strategies like central cores or outrigger systems manifest differently depending on regional pressures and priorities. For example, the relative concentration of freeform towers in Asia versus the dominance of setback geometries in North America are not merely aesthetic choices but responses to land use patterns, zoning codes, and climatic performance needs, which demands regionally specific architectural strategies.

In an era marked by rapid urbanization and environmental challenges, the insights from this study are expected to guide future high-rise construction practices in diverse urban contexts. The findings underscore the importance of balancing vertical growth with sustainable design principles and will provide valuable benchmarks for architects, urban planners, and policymakers engaged in shaping the skylines of emerging global cities. Through this comparative approach, the research offers a foundation for developing resilient, efficient, and culturally expressive skyscrapers that meet the evolving demands of urbanization across distinct regions.

MATERIALS AND METHODS

A case study methodology was applied to compile and analyze data from 133 skyscrapers. This approach, commonly employed in research for gathering qualitative and quantitative data alongside extensive literature reviews [46,47], facilitates an in-depth examination of the architectural and structural features of these projects. By analyzing each case individually, this method provides valuable insights into the unique design and structural characteristics of each tower, helping to reveal commonalities and differences across modern skyscraper designs and emerging patterns. Its flexibility allows for integrating various data sources, such as architectural blueprints and relevant documents, to achieve a thorough understanding of these high-rise structures.

The sample was assembled through a systematic and transparent selection process to ensure representativeness and eliminate potential selection bias. First, CTBUH database [48] was used as the sole data source to maintain consistency and comparability across all cases. Second, the inclusion threshold was set at an architectural height of ≥300 m, thereby focusing exclusively on supertall skyscrapers whose design and structural solutions differ substantially from shorter high-rise buildings. Third, only projects that were completed or topped-out as of August 2025 and had fully documented records for all target indicators—function, core type, architectural form, structural system, and primary structural material—were retained. Fourth, regional classification followed CTBUH's own geographical definitions, grouping cases into the Middle East, Asia, and North America. Any projects omitted from the dataset were excluded solely due to incomplete or unverified data, not for reasons of subjective preference. This process resulted in a final set of 133 skyscrapers (27 Middle East, 75 Asia, 31 North America), which constitutes the complete, verifiable population for the height threshold considered at the time of data collection.

In this research, a sample of 133 skyscrapers was selected from the CTBUH database [48], a widely respected resource on high-rise structures globally (Appendix A). CTBUH, an influential non-profit, actively promotes sustainable urban development and resilience in response to the challenges posed by accelerated urbanization and climate change. Renowned for setting industry standards for high-rise classification, the organization also confers titles such as "World's Tallest Building" and "Buildings of Distinction" to recognize outstanding architectural accomplishments. While the CTBUH database was the primary source for its authoritative, globally recognized, and standardized data framework, key variables—building height, completion year, and functional classification—were systematically cross-checked with multiple secondary sources, including official project websites, Emporis, and SkyscraperPage. This multi-source verification process was applied particularly in cases where discrepancies, missing values, or updates were identified, ensuring that the dataset reflected the most accurate and current information available. Such triangulation not only improved data consistency and completeness but also reduced the risk of transcription errors and source bias, thereby increasing the overall reliability and validity of the comparative analyses conducted in this study.

For this study, buildings over 300 m in height were categorized as "supertall," underscoring their significance and the advanced engineering and architectural expertise required for their creation. This study applies a descriptive statistical approach based on frequency distributions across key typological indicators. Inferential statistical methods (e.g., chi-square, ANOVA, regression analysis) were not employed, as the study was designed to establish a comparative typological baseline across regions rather than to test hypotheses or assess statistical significance.

In this study, the case sample was meticulously curated to provide a robust and representative examination of 133 skyscrapers (27 from Middle East, 75 from Asia, and 31 from North America) with varied functional purposes worldwide. While geographical limitations and access restrictions shaped the selection, the chosen sample was thoughtfully assembled to deliver an in-depth analysis of architectural and structural features of skyscrapers. The sample encompasses a diverse array of skyscrapers, as depicted in Figure 1, offering a comprehensive perspective on design and efficiency in tall structures globally.

Figure 1. Case studies on the world map (by authors).

The design of skyscrapers is guided by both architectural and structural requirements, where essential elements include core layout, building function and form, and the selection of structural systems and materials. For architectural considerations, this study adopts the core layout framework from [24], as illustrated in Figure 2a. Additionally, this paper classifies building forms into various distinct categories, shown in Figure 2b. Selecting an appropriate structural framework is crucial for skyscraper design. This article applies the structural classification presented by [38], depicted in Figure 2c. The choice of structural materials, such as steel, concrete, or composite systems, plays a critical role in defining component dimensions and spatial arrangement. In this context, the term ‘composite’ denotes skyscrapers where vertical load-bearing elements, including shear walls and columns, are constructed from combinations of concrete and steel.

The classification of architectural forms, core typologies, and structural systems in this study follows widely recognized frameworks established in the scholarly literature and professional practice guidelines. Architectural form categories (prismatic, tapered, freeform, setback, twisted) are adapted from [49–51], with modifications to align with the typological definitions used by CTBUH (2025). Structural system classifications (e.g., outriggered frame, tube, shear-frame, mega core, buttressed core) are based on the seminal work of [39,44,49–51] and the CTBUH system taxonomy [48], which are widely applied in comparative high-rise studies for their clarity and reproducibility. These frameworks were selected to ensure definitional consistency, methodological comparability, and direct applicability to all 133 cases in the dataset.

While other potentially important parameters—such as façade systems, energy-saving strategies, and structural damping devices—are indeed relevant to skyscraper performance, they were excluded from this analysis due to incomplete or inconsistent documentation across the entire sample in the CTBUH database [48]. Inclusion of such variables without full dataset coverage could compromise cross-regional comparability and introduce selection bias. Moreover, these parameters are often highly project-specific and context-dependent, making them more suitable for in-depth case studies or smaller-sample performance analyses. Future research could integrate such environmental and technological features by employing supplementary data sources and standardized classification schemes, enabling a more comprehensive correlation between typology, technology, and sustainability outcomes.

Table 1 shows regional Distribution of selected skyscrapers according to core planning, form, and structural system.

Table 1. Regional Distribution of selected skyscrapers by core planning, form, and structural system.

Design Parameter	Typological Classification	All %	Middle East (27)	%	Asia (75)	%	North America (31)	%
Core planning	Central	96%	26	96%	74	99%	28	90%
	External	2%	1	4%	1	1%	-	-
	Peripheral	2%	-	-	-	-	3	10%
Building form	Prismatic	28%	12	37%	17	23%	8	26%
	Setback	16%	2	7%	10	13%	9	29%
	Tapered	27%	2	7%	27	36%	7	23%
	Twisted	2%	1	4%	1	1%	1	3%
	Free	27%	10	45%	20	27%	6	19%
Structural system	Shear walled frame	12%	3	11%	1	1%	12	39%
	Mega Column	3%	2	7%	2	3%	-	-
	Mega Core	2%	2	7%	-	-	1	3%
	Outrigggered	62%	12	45%	57	76%	13	42%
	Tube	19%	7	26%	13	17%	5	16%
	Buttressed core	2%	1	4%	2	3%	-	-

Note: This analysis presents descriptive statistics only; no inferential tests of significance were applied.

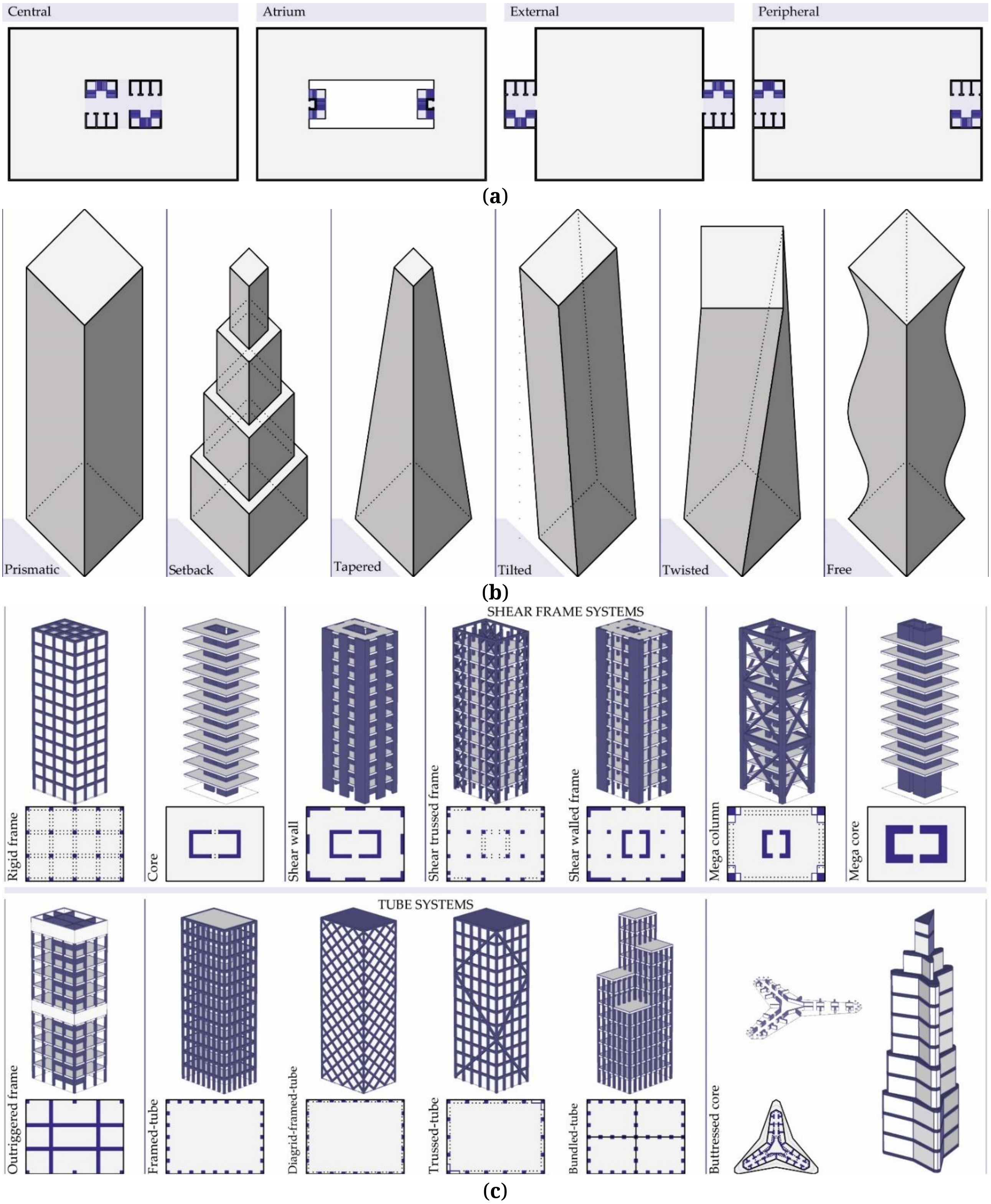

Figure 2. Classifications by (**a**) core planning; (**b**) form; and (**c**) structural system (by authors).

RESULTS

Main Architectural Design Parameters

This section presents a comprehensive quantitative analysis of architectural design parameters for a total of 133 skyscrapers in the Middle East (27 towers), Asia (75 towers), and North America (31 towers). The methodology involved multiplying the percentage values in Table 2 by the number of buildings in each region to produce the number of towers in each subcategory.

Table 2. Comparison of architectural design parameters.

Findings	Middle East	Asia	North America
Function	Residential (45%) Office (22%) Mixed-use (33%)	Residential (5%) Office (38%) Mixed-use (57%)	Residential (23%) Office (29%) Mixed-use (48%)
Core type	Central (96%) External (4%)	Central (99%) External (1%)	Central (90%) Peripheral (10%)
Form	Prismatic (45%) Setback (7%) Tapered (7%) Twisted (4%) Free (37%)	Prismatic (23%) Setback (13%) Tapered (36%) Twisted (1%) Free (27%)	Prismatic (26%) Setback (29%) Tapered (26%) Twisted (0%) Free (19%)

According to Table 2, functional distributions across the three regions reveal that in the Middle East, residential use is the most common, accounting for 45% of towers. This corresponds to 12 out of 27 towers. Mixed-use buildings represent 33%, or approximately 9 towers, while office buildings make up 22%, or 6 towers. In Asia, the predominant function is mixed-use, comprising 57% of the 75 towers, which equals 43 towers. Office towers are the second most common at 38%, or 29 towers, while residential buildings constitute only 5%, or approximately 4 towers. In North America, the distribution is more balanced. Mixed-use towers account for 48%, or 15 out of 31 towers. Office buildings make up 29%, or 9 towers, and residential use is reported in 23%, or 7 towers.

Considering the total 133 buildings, mixed-use towers represent the majority at 50.4%, which equals 67 towers, including Entisar Tower (Case #3, Dubai), Suzhou Zhongnan Center (Case #3, Suzhou), and Trump International Hotel & Tower (Case #29, Chicago). Office buildings, like CITIC Tower (Case #34, Beijing) and 30 Hudson Yards (Case #30, New York) comprise 33.1% of the sample, or 44 towers, and residential towers make up 16.5%, or 22 towers, including Elite Residence (Case #19, Dubai), 53 West 53 (Case #19, New York). Asia contributes the largest number of mixed-use buildings, with 43 out of 67 such towers, followed by North America with 15 and the Middle East with 9. Among the 44 office buildings, 29 are in Asia, 9 in North America, and 6 in the Middle East. Of the 22 residential towers, the Middle East contributes the highest number with 12, followed by North America with 7, and Asia with only 4.

Core typology distribution is another primary variable included in Table 2. In the Middle East, 96% of buildings use a central core system, which equals 26 towers, while 4%, or 1 tower, uses an external core. In Asia, the percentage of central core usage rises to 99%, or 74 towers, while 1%, or 1 tower, utilizes an external core. In North America, 90% of towers use central cores, amounting to 28 buildings, while 10%, or 3 towers, use a peripheral core layout.

Across the entire dataset, 128 out of 133 towers (96.2%) use a central core. External core systems are used in 2 towers (1.5%), while peripheral cores appear in 3 towers (2.3%). All external core towers are in the Middle East and Asia (one in each), while the three peripheral core towers are all found in North America. These figures confirm the overwhelming global dominance of central core systems in supertall architecture.

In the Middle East, prismatic forms are most prevalent at 45%, or 12 towers, including Marina 101 (Case #12, Dubai) and Marina 106 (Case #4, Dubai). Freeform shapes follow at 37%, or 10 towers. Setback and tapered forms each account for 7%, or 2 towers each. Twisted forms appear in only one building, Cayan Tower (Case #16, Dubai), constituting 4%. In Asia, tapered forms dominate with 36%, or 27 towers, including Ping an Finance Center (Case #41, Shenzhen). Freeform designs make up 27%, or 20 towers. Prismatic shapes constitute 23%, or 17 towers, as in the case of Changsha IFS Tower T1 (Case #36, Changsha). Setback forms are present in 13%, or 10 towers, while twisted forms are minimal at 1%, or 1 tower. In North America, setback forms lead at 29%, or 9 towers. Prismatic, like New York Times Tower (Case #32, New York), and tapered forms are each used in 26%, or 8 towers each. Freeform structures account for 19%, or 6 towers. There are no twisted towers in North America.

When the architectural form data is aggregated across all 133 towers in the dataset, the prismatic and tapered categories emerge as the most common, with 37 buildings respectively. These represent 27.8% of the total sample per category. Freeform designs follow closely, appearing in 36 towers, or 27.1% of the total. Setback forms are found in 21 towers, accounting for 15.8%. Twisted forms are the least utilized, with only 2 examples, comprising 1.5% of the global sample. The cumulative total for prismatic, tapered, and freeform buildings is 110 towers, which constitutes 82.7% of all tall buildings analyzed. This demonstrates a clear global preference for geometrically straightforward or aesthetically fluid shapes in skyscraper architecture. Setback forms are a secondary strategy, while twisted configurations are rare and largely absent from North American developments.

Among the 37 tapered towers, 27 are in Asia, 8 in North America, and 2 in the Middle East. Of the 37 prismatic towers, 17 are in Asia, 12 in the Middle East, and 8 in North America. The 36 freeform towers are distributed as 20 in Asia, 10 in the Middle East, and 6 in North America. Setback towers total 21, with 10 in Asia, 9 in North America, and 2 in the Middle East. The only two twisted towers are found in the Middle East and Asia—1 each.

Twisted towers are the least common, with only 2 examples globally—one each in the Middle East and Asia. North America has no twisted forms. In contrast, setback forms appear in all regions, with the highest concentration in North America (9 towers), followed by Asia (10 towers) and the Middle East (2 towers). Thus, setback designs are regionally more distributed, while twisted forms remain statistically rare.

Among the 128 central core towers, all five architectural forms are represented, including the rare twisted examples. This demonstrates that the central core system is compatible with all geometric configurations. The 3 peripheral core towers in North America occur mainly in prismatic and setback buildings. The 2 external core towers, one in Asia and one in the Middle East, are distributed across unique forms, likely prismatic or freeform, based on overall regional distribution.

Although Table 2 does not explicitly cross-reference function and form, the prevalence of mixed-use towers (67 total) across all form categories suggests flexibility in form selection. Residential towers, particularly in the Middle East, mostly appear as prismatic and freeform. Office towers, especially in Asia, are often associated with tapered and prismatic configurations.

To summarize the findings, mixed-use towers are the most common function in all regions combined, particularly dominating in Asia and North America. The central core typology is the global standard, used in over 96% of all towers. Three architectural forms—prismatic, tapered, and freeform—account for more than 80% of the global sample. Twisted forms are almost nonexistent, and setback forms are primarily North American. All numeric insights are derived from Table 2 using basic percentage-to-absolute conversions based on the number of towers per region. No interpretive, speculative, or contextual commentary has been applied. The section represents a strictly data-based description of architectural design distributions across a multinational skyscraper dataset.

Main Structural Design Parameters

This section presents a comprehensive quantitative analysis of structural design parameters for a total of 133 skyscrapers in the Middle East (27 towers), Asia (75 towers), and North America (31 towers). The methodology involved multiplying the percentage values in Table 3 by the number of buildings in each region to produce the number of towers in each subcategory.

Table 3. Comparison of structural design parameters.

Findings	Middle East	Asia	North America
Structural material	Concrete (70%) Composite (30%) Steel (0%)	Concrete (18%) Composite (79%) Steel (3%)	Concrete (55%) Composite (39%) Steel (6%)
Structural system	Outriggered frame (44%) Tube (26%) Mega column & core (15%) Shear-frame (11%) Buttressed core (4%)	Outriggered frame (76%) Tube (17%) Buttressed core (3%) Mega column & core (3%) Shear-frame (1%)	Outriggered frame (42%) Tube (16%) Mega column & core (3%) Shear-frame (39%) Buttressed core (0%)

In the Middle East, the most widely used structural system is the outriggered frame, found in 44% of the towers, which equates to 12 buildings, including Burj Mohammed Bin Rashid (Case #14, Abu Dhabi), and Central Park Tower (Case #14, New York). Tube system follows at 26%, or approximately 7 towers, as in the cases of Princess Tower (Case #17, Dubai) and 432 Park Avenue (Case #26, New York) while the mega column and core system is used in 15%, or 4 towers, including Nakheel Tower (Case #5, Dubai). The shear-frame system appears in 11%, equal to 3 towers, and the buttressed core system is used in 4%, corresponding to 1 tower, Burj Khalifa (Case #22, Dubai). This suggests a moderate distribution across system types, with a clear preference for the outriggered approach.

In Asia, there is a clear structural pattern: the outriggered frame system dominates the region with 76% of skyscrapers, which corresponds to 57 towers. The tube system is used in 17% of towers, or 13 buildings. Both mega column and core and buttressed core systems are each used in 3% of buildings, equating to 2 towers each. The shear-frame system is minimally used, present in only 1 tower, accounting for 1%. This indicates a strong regional standardization around a single structural solution.

In North America, a more balanced structural distribution is evident. The outriggered frame is still the most frequent system at 42%, or 13 towers. However, shear-frame systems are nearly as prevalent, found in 39%, or 12 towers. The tube system appears in 16% of buildings, corresponding to 5 towers, and the mega column and core system is used in 3%, or 1 building. No buttressed core systems are recorded in this region. This variety suggests greater structural diversity, perhaps influenced by historical engineering practices and local regulations.

Across all 133 towers, the outriggered frame system is clearly dominant, employed in 82 buildings, which represents 61.7% of the sample. It is also the only system that is significantly represented in all three regions. The tube system is the second most frequent, used in 25 towers (18.8%). The shear-frame system is present in 16 towers (12%), while the mega column and core system is seen in 7 buildings (5.3%). The buttressed core system is the rarest, applied in just 3 towers (2.3%), all outside North America.

When the regional distribution of structural systems is examined, it becomes clear that Asia leads in the number of outriggered frame towers (57), followed by North America (13) and the Middle East (12). The tube system is relatively balanced across regions: 13 towers in Asia, 7 in the

Middle East, and 5 in North America. The shear-frame system shows strong regional concentration, with 12 of its 16 global examples in North America, suggesting a historically rooted engineering preference. Mega column and core systems are mostly seen in the Middle East (4 towers), with fewer examples in Asia (2) and North America (1). The buttressed core system only appears in Asia (2 towers) and the Middle East (1 tower).

Beyond structural systems, Table 3 also includes information on primary construction materials. In the Middle East, concrete dominates, used in 70% of towers, or approximately 19 buildings, while composite structures make up the remaining 30%, or 8 buildings. There are no instances of steel as the primary material in this region. In Asia, the material profile is reversed: composite materials dominate at 79% (about 59 towers), followed by concrete at 18% (about 14 towers) and steel at 3% (about 2 towers). In North America, concrete accounts for 55% of the towers (about 17 towers), composite 39% (about 12 towers), and steel 6% (about 2 towers).

These material distributions reflect regional preferences and supply-chain practices. Composite systems are common in Asia, where speed of construction and performance optimization are prioritized. In contrast, North America uses a blend of concrete and steel, aligning with its higher frequency of shear-frame and tube systems, which are often steel-intensive. The Middle East's dominance in concrete may reflect regional cost efficiency and climate adaptation strategies, especially in megastructures using mega columns and core systems.

In conclusion, the data show that the outriggered frame system is the global standard in supertall buildings, appearing in over 60% of the sample and leading in all three regions. The tube and shear-frame systems provide additional flexibility and are applied in select regional contexts, particularly North America. Material choices follow similar regional patterns, with Asia relying on composite, North America balancing concrete and steel, and the Middle East focused on concrete systems. These patterns reflect both technological standardization and regional adaptation in the evolution of skyscraper structural design.

DISCUSSION

The comparative analysis of skyscraper design patterns across the Middle East, Asia, and North America reveals distinct architectural and structural preferences that are shaped by a combination of regional engineering practices, urbanization dynamics, material economies, and climate responsiveness.

In the Middle East, the prevalence of residential towers (45%) and the significant use of prismatic and freeform geometries were observed. Prismatic forms offer simplicity in load distribution and cost-effective repetition, while freeform structures often serve as symbolic icons of economic ambition and modernity, such as the Burj Khalifa. The dominance of central core systems (96%) is consistent with global patterns in seismic safety and vertical circulation efficiency. Structurally, the Middle East's preference for outriggered frame systems (44%) aligns with the region's aspiration for height and slenderness, enabling tall residential towers to resist wind loads and control lateral displacement. Material-wise, the overwhelming use of concrete (70%) in the Middle East is attributable to its local availability, cost-effectiveness in hot climates, and compatibility with massing strategies such as mega columns. In addition to these practical considerations, the Middle East's reliance on concrete has been interpreted not only as a response to local climatic and cost conditions but also as an expression of monumentality and permanence in the regional architectural narrative [52].

Asia demonstrates the most streamlined high-rise strategy, with 76% of buildings adopting the outriggered frame system and 79% utilizing composite materials. This convergence points to a mature and industrialized construction ecosystem where high-rise design is driven by efficiency and scale. Functionally, mixed-use towers dominate (57%), reflecting the dense, polycentric urbanism of cities like Shanghai, Shenzhen, and Kuala Lumpur. Tapered forms are most common (36%), often serving aerodynamic and symbolic purposes, as seen in supertall towers like the Shanghai Tower. The near-universal adoption of central cores (99%) supports high floor area efficiency and aligns with regional fire-safety codes. Composite systems are popular due to their balance of speed (steel framing) and fire resistance (concrete cores), enabling developers to achieve faster construction cycles in highly competitive markets.

In contrast, North America exhibits the most diverse structural and architectural patterns. While mixed-use towers also dominate here (48%), the distribution among office (29%) and residential (23%) functions is more balanced. Setback forms, the most prevalent in North America, reflect the legacy of urban design policies such as New York City's 1916 Zoning Resolution, which mandated stepped building forms for sunlight access—a typology widely discussed in urban studies [53]. The frequent use of shear-frame systems (39%) is distinctive to North America, reflecting legacy practices in steel construction and seismic-resilient designs dating back to the mid-20th century. Material use shows a balanced mix—concrete (55%), composite (39%), and steel (6%)—illustrating the region's adaptability to different structural logics. The relatively higher incidence of peripheral cores (10%) also indicates a willingness to diversify internal space planning to accommodate flexible programming needs.

Functionally, mixed-use towers are predominant across all regions, but their distribution reflects local market conditions. In Asia, high land value and vertical zoning laws incentivize stacking multiple uses within a single footprint, encouraging the integration of retail, hotel, office, and residential spaces. In the Middle East, the large share of residential towers mirrors a demand for high-rise living within luxury-driven real estate markets. In North America, a more balanced mix of uses suggests mature real estate ecosystems where office, residential, and commercial developments coexist but are still governed by distinct financial and regulatory frameworks.

The dominance of central core systems (96.2% globally) across all architectural forms and regions suggests that despite regional differences in style and function, the core typology remains a universally optimal solution for supertall structures. Central cores offer advantages in structural stability, MEP distribution, and fire safety, especially in jurisdictions with strict building codes. The rare use of peripheral and external cores—only 5 towers total—signals either experimental design intentions or highly specific spatial requirements, such as in unique office towers or mixed-use developments.

Regionally, structural system selections are shaped by a combination of seismic considerations, wind engineering, and developer familiarity. The outriggered frame's global dominance (61.7%) is not accidental; it provides a practical solution for resisting lateral forces and allows architectural flexibility in tower massing. Asia's overwhelming reliance on this system reflects economies of scale and design standardization. In North America, the presence of both shear-frame and outriggered systems indicates a transitional phase in high-rise construction, where newer towers adopt modern systems, but older paradigms still influence design. The Middle East's hybrid adoption of outriggered, tube, and mega column systems shows an evolving market that blends imported engineering models with regional experimentation.

Material usage patterns reinforce structural preferences and regional economic conditions. Asia's dominance in composite structures reflects technological advancement and labor specialization, particularly in pre-fabrication and hybrid assembly. The Middle East favors concrete due to cost efficiency, thermal mass benefits, and local production capacity. North America's mix of concrete and steel stems from long-standing traditions in steel-framed skyscrapers and evolving green building codes that encourage flexibility in material sourcing and lifecycle cost analysis.

The rarity of twisted and buttressed forms and systems (each below 3% of global use) demonstrates the limited scalability of structurally complex or cost-intensive typologies. While visually striking, twisted towers often require bespoke engineering and incur higher wind loads, making them suitable only for iconic projects with generous budgets. Similarly, the buttressed core—most famously employed in the Burj Khalifa—is structurally efficient for extreme heights but overly specialized for mid-height supertalls and cost-sensitive markets.

In summary, skyscraper design patterns in the Middle East, Asia, and North America reflect a blend of universal engineering logic and region-specific constraints. While core typology and outriggered systems form the backbone of global supertall architecture, regional differences in form, function, and material highlight the importance of contextual adaptation.

This analysis underscores the need for more integrated frameworks that combine morphological, structural, and environmental data to holistically evaluate skyscraper design evolution.

While this study’s primary focus is on typological and structural comparisons, the findings also hold direct implications for the sustainability of tall building design across economic, environmental, and social dimensions [54–56]. In terms of economic sustainability, the predominance of mixed-use configurations in Asia (57%) and North America (48%) supports high land-use efficiency and diversified revenue streams, which can improve the long-term financial viability of high-rise developments. In the Middle East, the higher share of residential towers (45%) reflects a luxury-driven market but also raises questions about adaptability and resilience to market fluctuations. Structural system choices such as outriggered frames, dominant in Asia (76%), are often associated with faster construction cycles and reduced structural material usage per unit floor area, thus potentially lowering construction costs [44].

In terms of environmental sustainability, material preferences reveal distinct regional environmental trade-offs. Asia’s reliance on composite systems balances the structural efficiency of steel with fire resistance and thermal mass of concrete, potentially optimizing operational energy performance. The Middle East’s heavy use of concrete (70%) may provide thermal benefits in hot–arid climates but comes with a higher embodied carbon footprint compared to steel or composite systems. In North America, the mix of concrete, composite, and steel aligns with both historical construction traditions and emerging low-carbon design strategies. Architectural form also influences energy performance: tapered forms can reduce wind loads and envelope surface area, while freeform geometries, though iconic, may increase façade complexity and associated thermal losses [45].

While this study did not quantitatively analyze climatic variables, the observed regional design preferences may in part be attributed to environmental factors. For instance, the prevalence of tapered forms in Asia could be linked to wind mitigation strategies in typhoon-prone coastal areas; the dominance of concrete in the Middle East may also reflect thermal mass advantages in hot–arid climates; and the higher share of setback forms in North America may be influenced by both zoning codes and snow/wind load considerations in temperate and cold regions. As [57] emphasizes, such form–climate relationships are often reinforced by regulatory frameworks and technological advancements, for example Singapore’s climate-adaptive skyscraper guidelines or the integration of smart façade systems to optimize thermal performance in extreme climates. These precedents indicate that climate-sensitive design is not merely incidental but increasingly intentional, merging environmental performance goals with cultural and economic drivers.

In terms of social sustainability, high-rise design patterns also influence social well-being. Mixed-use skyscrapers contribute to vertical urbanism, integrating residential, commercial, and leisure spaces in a single footprint, which can enhance urban vibrancy and reduce commuting distances. Setback forms, prevalent in North America, historically responded to daylight access regulations, indirectly improving public realm quality. In the Middle East, landmark freeform towers often function as symbols of cultural identity and international presence, fostering place attachment and civic pride. Core typology also has social implications—central cores dominate globally (96.2%), offering efficient vertical circulation, safety, and adaptability to diverse occupancy types.

Overall, while the present research did not explicitly quantify sustainability performance, the observed typological patterns have clear economic, environmental, climatic, and social consequences. Integrating sustainability performance metrics—such as embodied carbon, lifecycle cost analysis, and post-occupancy social impact assessments—into future typological studies would enhance the relevance of such analyses for sustainable urban development policy and practice.

CONCLUSIONS

This study has presented a comparative, data-driven analysis of 133 supertall towers across three global regions—Middle East, Asia, and North America—focusing on measurable architectural and structural attributes. By relying exclusively on quantitative data, the research provides objective insight into regional patterns in function, core layout, form, and structural systems.

Key findings include the dominance of mixed-use buildings globally, with Asia and North America leading this category. The Middle East diverges, showing a greater share of residential towers. Central core typology is nearly universal, confirming its standardization in tall building design.

In terms of architectural form, prismatic, tapered, and freeform geometries together comprise over 80% of all towers. Asia leads in tapered and freeform forms, while the Middle East prefers prismatic designs. North America is distinct in its preference for setback geometries.

Structurally, the outriggered frame system dominates globally. Asia contributes the majority of these, followed by the Middle East and North America. Tube systems and shear-frame structures show more regional specificity, with the latter concentrated almost entirely in North America.

This study provides a comparative overview of skyscraper design patterns across three major regions, yet certain limitations should be acknowledged. The dataset comprises 133 towers over 300 m, completed or topped out between 1990 and 2025, which, while substantial, may not fully capture design diversity—particularly in underrepresented regions. For consistency, the analysis focused on a core set of indicators—function, core type, form, structural system, and material—excluding other potentially valuable parameters such as gross building area, floor-to-floor height, building shape factor, area usage ratio, construction unit cost, façade systems, structural damping, energy strategies, and climatic variables (e.g., temperature extremes, wind exposure, seismicity, precipitation) due to incomplete or unverified data across all cases in the CTBUH database. Incorporating such metrics without full coverage could compromise cross-regional comparability and introduce selection bias. Moreover, while the study offers contextual insights, the absence of direct quantitative measures for environmental and regulatory influences limits causal interpretations. Nevertheless, the temporal span of the dataset provides a foundation for longitudinal research, and future work could integrate supplementary datasets, harmonized environmental information, and multivariate statistical methods to explore the interplay between typology, performance, and context—advancing a more holistic understanding of skyscraper design and sustainability across diverse economic, climatic, and cultural settings.

Future research can build on the present typological baseline by adopting several operational strategies. First, expanding the variable set to include façade system classifications, energy-saving technologies, vertical transportation efficiency, and post-occupancy performance indicators would allow for a more holistic evaluation of skyscraper design outcomes. Second, integrating environmental datasets, global wind hazard maps, and seismic risk assessments—would enable quantitative testing of climate-related design adaptations. Third, applying longitudinal and temporal stratification methods could reveal how typological preferences shift over time in response to economic cycles, regulatory changes, and technological innovations. Fourth, triangulating data from multiple sources, including municipal building permits, architectural firm archives, and satellite imagery, would enhance completeness and reduce reliance on a single database. Finally, interdisciplinary collaborations between architects, structural engineers, urban economists, and social scientists could produce integrated performance indices combining economic, environmental, and social sustainability dimensions. By pursuing these targeted directions, future studies can deepen the link between skyscraper typologies and the broader goals of sustainable, resilient urban development.

In conclusion, this study provides a foundational empirical reference for skyscraper typologies. It confirms a growing global convergence in some technical solutions, such as core layout and structural strategies, while also revealing regionally distinct patterns in form and function that merit further interdisciplinary investigation.

DATA AVAILABILITY

All data generated from the study are available in the manuscript.

AUTHOR CONTRIBUTIONS

Conceptualization, HEI; methodology, HEI and ÖNA; software, HEI; formal analysis, HEI and ÖNA; investigation, HEI and ÖNA; writing—

original draft preparation, HEI; writing—review and editing, HEI and ÖNA; supervision, HEI. All authors have read and approved the final version of the manuscript.

CONFLICTS OF INTEREST

The authors declare that there is no conflicts of interest.

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APPENDIX A

Table A1. The building list, categorized by region, ordered according to country, city, height (in meters), number of stories, and year of completion in descending order.

#	Building Name (Middle East)	Country	City	Height (Meters)	# of Stories	Completion Date
1	Il Primo Tower 1	UAE	Dubai	356	79	UC
2	Al Wasl Tower	UAE	Dubai	300	64	UC
3	Entisar Tower	UAE	Dubai	577	122	OH
4	Marina 106	UAE	Dubai	445	104	OH
5	Nakheel Tower	UAE	Dubai	1000	200	NC
6	Dynamic Tower	UAE	Dubai	388	80	NC
7	PIF Tower	Saudi Arabia	Riyadh	385	72	2021
8	Amna Tower	UAE	Dubai	307	75	2020
9	Noora Tower	UAE	Dubai	307	75	2019
10	NBK Tower	Kuwait	Kuwait City	300	61	2019
11	DAMAC Heights	UAE	Dubai	335	88	2018
12	Marina 101	UAE	Dubai	425	101	2017
13	ADNOC Headquarters	UAE	Abu Dhabi	342	65	2015
14	Burj Mohammed Bin Rashid	UAE	Abu Dhabi	381	88	2014
15	Burj Rafal	Saudi Arabia	Riyadh	307	68	2014
16	Cayan Tower	UAE	Dubai	306	73	2013
17	Princess Tower	UAE	Dubai	413	101	2012
18	23 Marina	UAE	Dubai	392	88	2012
19	Elite Residence	UAE	Dubai	380	87	2012
20	Al Hamra Tower	Kuwait	Kuwait City	413	80	2011
21	The Torch	UAE	Dubai	352	86	2011
22	Burj Khalifa	UAE	Dubai	828	163	2010
23	Ocean Heights	UAE	Dubai	310	83	2010
24	Almas Tower	UAE	Dubai	360	68	2008
25	Aspire Tower	Qatar	Doha	300	36	2007
26	Kingdom Centre	Saudi Arabia	Riyadh	302	41	2002
27	Emirates Tower One	UAE	Dubai	355	54	2000
#	**Building Name (Asia)**	**Country**	**City**	**Height (Meters)**	**# of Stories**	**Completion Date**
1	Merdeka PNB118	Malaysia	Kuala Lumpur	644	118	UC
2	Greenland Jinmao International Financial Center	China	Nanjing	499	102	UC
3	Wuhan Greenland Center	China	Wuhan	475	97	UC
4	Chengdu Greenland Tower	China	Chengdu	468	101	UC
5	Autograph Tower	Indonesia	Jakarta	382	75	UC
6	Guiyang World Trade Center Landmark Tower	China	Guiyang	380	92	UC
7	Spring City 66	China	Suzhou	358	77	UC
8	CITIC Financial Center Tower 1	China	Shenzhen	312	-	UC
9	Supernova Spira	India	Noida	300	80	UC
10	Shimao Riverside Block D2b	China	Wuhan	300	53	UC
11	Greenland Group Suzhou Center	China	Tianjin	358	83	OH
12	Goldin Finance 117	China	Tianjin	596	128	OH
13	Evergrande Hefei Center 1	China	Hefei	518	112	OH
14	R&F Guangdong Building	China	Tianjin	468	91	OH
15	Chongqing Tall Tower	China	Chongqing	431	101	OH

16	Haikou Tower 1	China	Haikou	428	94	OH
17	Palace Royale	Mumbai	India	320	88	OH
18	Suzhou Zhongnan Center	China	Suzhou	729	137	NC
19	Busan Lotte Town Tower	South Korea	Busan	510	107	NC
20	World One	Mumbai	India	442	117	NC
21	Guangxi China Resources Tower	China	Nanning	402	86	2020
22	Shum Yip Upperhills Tower 1	China	Shenzhen	388	80	2020
23	Hengqin International Finance Center	China	Zhuhai	337	69	2020
24	Shenzhen Bay Innovation and Technology Centre Tower 1	China	Shenzhen	311	69	2020
25	Tianjin CTF Finance Centre	China	Tianjin	530	97	2019
26	The Exchange 106	Malaysia	Kuala Lumpur	446	95	2019
27	LCT The Sharp Landmark Tower	South Korea	Busan	411	101	2019
28	Golden Eagle Tiandi Tower A	China	Nanjing	368	77	2019
29	The Center	China	Kunming	349	61	2019
30	LCT The Sharp Residential Tower A	Korea	Busan	339	85	2019
31	LCT The Sharp Residential Tower B	Korea	Busan	333	85	2019
32	Golden Eagle Tiandi Tower B	China	Nanjing	328	68	2019
33	Golden Eagle Tiandi Tower C	China	Nanjing	300	60	2019
34	CITIC Tower	China	Beijing	528	108	2018
35	Vincom Landmark 81	Vietnam	Ho Chi Minh City	461	81	2018
36	Changsha IFS Tower T1	China	Changsha	452	94	2018
37	China Resources Tower	China	Shenzhen	393	68	2018
38	Hanking Center Tower	China	Shenzhen	359	65	2018
39	One Shenzhen Bay Tower 7	China	Shenzhen	341	78	2018
40	Guangfa Securities Headquarters	China	Guangzhou	308	60	2018
41	Ping an Finance Center	China	Shenzhen	599	115	2017
42	Lotte World Tower	South Korea	Seoul	554	123	2017
43	Hon Kwok City Center	China	Shenzhen	329	80	2017
44	Sinar Mas Center 1	China	Shanghai	320	65	2017
45	Guangzhou CTF Finance Centre	China	Guangzhou	530	111	2016
46	Chongqing IFS T1	China	Chongqing	316	63	2016
47	MahaNakhon	China	Bangkok	314	79	2016
48	Shanghai Tower	China	Shanghai	632	128	2015
49	Fortune Center	China	Guangzhou	309	68	2015
50	Jiangxi Nanchang Greenland Central Plaza, Parcel A	China	Nanchang	303	59	2015
51	Jiangxi Nanchang Greenland Central Plaza, Parcel B	China	Nanchang	303	59	2015
52	Abeno Harukas	Japan	Osaka	300	60	2014
53	Deji Plaza	China	Nanjing	324	62	2013
54	Pearl River Tower	China	Guangzhou	309	71	2013
55	Keangnam Hanoi Landmark Tower	Vietnam	Hanoi	328	72	2012
56	Leatop Plaza	China	Guangzhou	303	64	2012
57	KK 100	China	Shenzhen	441	98	2011
58	Tianjin World Financial Center	China	Tianjin	337	75	2011
59	International Commerce Centre	China	Hong Kong	484	108	2010
60	Zifeng Tower	China	Nanjing	450	66	2010
61	Guangzhou International Finance Center	China	Guangzhou	438	103	2010
62	China World Tower	China	Beijing	330	74	2010
63	Shanghai World Financial Center	China	Shanghai	492	101	2008
64	Shimao International Plaza	China	Shanghai	333	60	2006
65	Nina Tower	China	Hong Kong	320	80	2006
66	TAIPEI 101	Taiwan	Taipei	508	101	2004
67	Two International Finance Center	China	Hong Kong	412	88	2003
68	Menara TM	Malaysia	Kuala Lumpur	310	55	2001
69	Petronas Twin Tower 1	Malaysia	Kuala Lumpur	452	88	1998
70	Petronas Twin Tower 2	Malaysia	Kuala Lumpur	452	88	1998
71	OKO - Residential Tower	China	Hong Kong	346	73	1998
72	CITIC Plaza	China	Guangzhou	390	80	1996
73	Shun Hing Square	China	Shenzhen	384	69	1996
74	Central Plaza	China	Hong Kong	374	78	1992
75	Bank of China Tower	China	Hong Kong	367	72	1990
#	**Building Name (North America)**	**Country**	**City**	**Height (Meters)**	**# of Stories**	**Completion Date**
1	Torre Rise	Mexico	Monterrey	475	88	UC
2	JPMorgan Chase World Headquarters	USA	New York	423	60	UC
3	SkyTower at Pinnacle One Yonge	Canada	Toronto	345	105	UC
4	740 8th Avenue	USA	New York	325	52	UC
5	Waldorf Astoria Hotel and Residences Miami	USA	Miami	317	98	UC
6	Waterline	USA	Austin	311	74	UC

7	The One	Canada	Toronto	309	85	UC
8	520 Fifth Avenue	USA	New York	305	76	UC
9	Concord Sky	Canada	Toronto	300	85	UC
10	Chicago Spire	USA	Chicago	609	150	NC
11	The Brooklyn Tower	USA	New York	325	74	2023
12	The Spiral	USA	New York	314	65	2022
13	111 West 57th Street	USA	New York	435	84	2021
14	Central Park Tower	USA	New York	472	98	2020
15	One Vanderbilt Avenue	USA	New York	427	62	2020
16	The St. Regis Chicago	USA	Chicago	363	101	2020
17	T.Op Corporativo	Mexico	Monterrey	305	62	2020
18	30 Hudson Yards	USA	New York	387	73	2019
19	53 West 53	USA	New York	320	77	2019
20	35 Hudson Yards	USA	New York	305	72	2019
21	One Manhattan West	USA	New York	304	67	2019
22	Comcast Technology Center	USA	Philadelphia	339	59	2018
23	3 World Trade Center	USA	New York	329	69	2018
24	Salesforce Tower	USA	San Francisco	326	61	2018
25	Wilshire Grand Center	USA	Los Angeles	335	62	2017
26	432 Park Avenue	USA	New York	426	85	2015
27	One World Trade Center	USA	New York	541	94	2014
28	One57	USA	New York	306	75	2014
29	Trump International Hotel & Tower	USA	Chicago	423	98	2009
30	Bank of America Tower	USA	New York	366	55	2009
31	New York Times Tower	USA	New York	319	52	2007

Note on abbreviations: “UC” indicates “Under Construction,” “OH” indicates “On Hold,” “NC” indicates “Never Completed”.

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