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Evaluating Space Efficiency of Tall Buildings in Turkey

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Abstract: In response to the increasing building demands in Turkey, particularly in the metropolitan area of Istanbul, followed by other major cities such as Ankara and Izmir, the expansion of construction zones has led to the emergence of tall towers as a pragmatic solution. The design and implementation of tall buildings require newer technologies and interdisciplinary collaboration in aspects such as facade installation, vertical circulation solutions, and fire systems, compared to low-rise buildings. In spite of the proliferation of skyscrapers, there is a noticeable lack of thorough study on space efficiency in Turkey's tall buildings. This article aims to fill this significant gap in the literature. The research method employed in this study focuses on a case study of 54 modern towers constructed in Turkey between 2010 and 2023, ranging in height from 147 to 284 m. Key findings are as follows: (1) residential use, central core, and prismatic forms are the most prevalent architectural preferences; (2) the most preferred structural material and system are concrete and the shear-walled frame system, respectively; (3) average space efficiency and the percentage of core-to-gross-floor area (GFA) were 78% and 19%, respectively, with measurement ranges varying from a minimum of 64% and 9% to a maximum of 86% and 34%. This paper will provide insight for construction stakeholders, especially architects, for sound planning decisions in the development of Turkish tall buildings.

Keywords: tall building; space efficiency; function; form; core planning; structural system and material; Turkey

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Citation: Aslantamer, Ö.N.; Ilgın, H.E. Evaluating Space Efficiency of Tall Buildings in Turkey. *Buildings* **2024**, *14*, 2138. https://doi.org/10.3390/buildings14072138

Received: 9 June 2024
Revised: 6 July 2024
Accepted: 10 July 2024
Published: 11 July 2024

1. Introduction

The concept of a densifying metropolis characterized by tall building typology addresses the urgent issues of urban overcrowding and rural depopulation by promoting a strategic redistribution of populations and the improvement of infrastructure in underutilized regions [1]. This involves the restructuring of over-densified urban neighborhoods, relocating poorly occupied regions, and revitalizing obsolete urban spaces to foster socio-spatial filtering and equitable population redistribution. Key strategies include strengthening mobility infrastructure and services to attract and retain populations in both urban and rural areas, promoting sustainable local resources, and encouraging family-led initiatives for population stabilization. The overarching aim is to create balanced, resilient, and cooperative urban–rural networks that enhance livability and ecological sustainability while mitigating the socio-economic inequalities exacerbated by current urbanization trends.

As cities expand due to natural population growth and migration, the demand for housing and urban services intensifies, especially in densely populated urban centers, necessitating the development of new high-rise building projects [2,3]. This has led to the adoption of innovative urban renewal strategies, such as over-elevation, which involves the construction of lightweight housing modules on the rooftops of existing buildings. This strategy is particularly relevant for historic city centers where buildings are often aging and in need of significant maintenance and upgrades. Over-elevation not only provides new housing units but also revitalizes these older structures, bringing them up to contemporary standards of comfort and efficiency. This dual benefit optimizes the use of urban space by increasing residential capacity without the need for expanding supply and transport networks or constructing new infrastructure. Such an approach supports sustainable urban development by maximizing existing resources and reducing the environmental and economic costs associated with building anew. However, the practice of over-elevation comes with its own set of challenges. Socially, the introduction of new residents into established communities can lead to tensions and integration issues, as the dynamics and demographics of neighborhoods change. Technically, the process requires advanced construction techniques and careful consideration of the existing building's structural integrity. Not all buildings are suitable for over-elevation, and the feasibility of such projects is often contingent on specific local regulations and the condition of the existing structures.

Overall, rapid growth in urban populations, along with the social and cultural changes linked to urbanization, has significantly increased the need for residential and office spaces [4–6]. This heightened demand, combined with the limited supply of affordable urban land, economic development, and technological advancements, has led to the vertical expansion of buildings [7–9]. The progress in construction technology has notably contributed to the rise of skyscrapers. Beginning in the late 19th century with buildings reaching up to 50 m and 10–12 stories, known as the first skyscrapers, these structures have evolved over the last century to reach nearly 1000 m and 160–170 stories. Originally unique to North America, skyscrapers are now prevalent in major cities around the globe [10].

In Turkey, the trend toward constructing taller buildings is also notable, with cities like Istanbul, Ankara, and Izmir emerging as major urban centers with a significant presence of skyscrapers [11]. Currently, Turkey is ranked 14th globally for buildings exceeding 150 m, and 18th for those over 200 m [12]. Although there are ongoing projects for structures surpassing 300 m, these have not yet been completed, preventing Turkey from appearing in the rankings for this height category. Nevertheless, Istanbul boasts the maximum number of towers in the country, ranking 29th globally and first in both Europe and Turkey for buildings taller than 150 m [12].

These structures bring complex demands for structural systems, facade systems, installations, vertical circulation, operational systems, and fire safety measures [13–16]. Tall buildings significantly influence local traffic, infrastructure, climate, landscape, city skyline, and communication systems [17]. Before deciding to construct a tall building, it is essential to evaluate the potential adverse social, economic, and ecological impacts on the surrounding area. Due to their height, towers are particularly susceptible to lateral forces from wind and seismic activity, requiring specialized knowledge of these factors during the design and construction phases [18].

In Turkey, the efficient utilization of space in skyscrapers is crucial due to economic, social, environmental, and aesthetic considerations. High land prices, especially in metropolitan areas like Istanbul, necessitate the optimal use of every square meter [19]. As population density rises, skyscrapers need to accommodate more people within limited spaces, helping to reduce urban sprawl and related issues such as traffic congestion and environmental degradation [20]. In big cities in Turkey, effective space utilization promotes environmental sustainability by minimizing land consumption and reducing energy use for heating, cooling, and lighting. Well-designed skyscrapers also enhance the city's identity and economic and cultural significance by maintaining aesthetically pleasing appearances. Projects such as Kanyon and Zorlu Center in Istanbul exemplify this approach to combining aesthetic and functional efficiency [21]. Additionally, efficient layout plans optimize the placement of infrastructure and services, ensuring functionality, accessibility, and ease of maintenance [22]. Overall, space efficiency in Turkey's skyscrapers is essential for maximizing revenue potential, accommodating growing populations, protecting the environment, maintaining urban aesthetics, and ensuring efficient building operations and services.

Comprehensive research on space utilization in Turkish skyscrapers is notably sparse. This study fills this void by analyzing 54 tall buildings in major Turkish cities like Istanbul, Ankara, and Izmir. The primary goal is to identify the main architectural and structural features that impact spatial efficiency. The analysis examines aspects such as function, form, service core design, load-bearing systems, and materials, along with their influence on space usage. This research aims to offer valuable knowledge to construction professionals, particularly architects, to aid in making informed planning decisions for the development of tall structures in Turkey.

This study concentrates exclusively on space efficiency, deliberately omitting considerations of sustainable design, such as energy efficiency, environmental sustainability, and disaster vulnerability. The rationale for this exclusion lies in the insufficient data available across all case studies, which precludes a comprehensive analysis of these parameters. By narrowing the focus to space efficiency, the research aims to provide a more precise and detailed examination of this particular aspect without the confounding variables introduced by incomplete information on sustainability issues.

2. Literature Survey

The literature on building space utilization is fragmented, covering various building types and their spatial efficiencies with distinct focuses. For instance, Okbaz and Sev [23] developed a model for office buildings, highlighting the efficiency of tapered forms, whereas Tuure and Ilgın [24] investigated mid-rise wooden apartment buildings, noting a spatial efficiency range of from 78% to 88% without clear floor-number correlations. Residential structures in Kabul, as studied by Ibrahimy et al. [25], often fail to meet space standards due to design and regulatory issues, while [26] proposed smart technologies to enhance urban housing efficiency. Service core design trends in supertall office buildings were examined by Ilgın [27], and Hamid et al. [28] identified optimal land use for single-family homes in Sudan, emphasizing corner plots. Spatial efficiency in hotel design, especially in larger spaces, was underscored by Suga [29].

Further, Ilgın [30], and subsequent studies by Ilgın [31,32], explored spatial optimization across building types, finding central core configurations and externally framed systems common, with efficiency decreasing with height. Prismatic structure parameters and their impact on core and load-bearing systems were detailed by Arslan Kılınç [33]. Stakeholder involvement via a web-based tool to enhance spatial efficiency was proposed by Von Both [34], while Höjer and Mjörnell [35] discussed digitalization's role in optimizing interior spaces. Lease span and corner configurations impacting efficiency were investigated by Nam and Shim [36], and Zhang et al. [37] highlighted free-form designs for increased solar gain in cold regions. Office tower design elements favoring externally framed systems and central cores were concluded by Sev and Özgen [38], with cost and climate control considerations emphasized by Saari et al. [39]. Mixed-use tower studies by Kim and Elnimeiri [40] stressed the importance of structural, energy, and spatial efficiency, along with optimal elevator allocation.

Geometric properties in skyscraper designs, such as prismatic and tapered forms, and their effect on spatial efficiency were explored by Ilgın and Aslantamer [41] and Ilgın [42], while Ilgın [43] and Ilgın [44] focused on cultural and environmental factors in supertall towers in the Middle East and Asia, respectively. Ilgın's comprehensive analysis of 135 supertall towers provided best practices and common challenges [45]. The unique spatial dynamics of timber construction in residential and office towers were examined by Ilgın and Aslantamer [46] and Aslantamer and Ilgın [47], emphasizing layout flexibility and material properties. This body of research collectively aims to bridge the existing gap in the comprehensive study of space efficiency across various high-rise constructions.

Overall, the literature on building space utilization is diverse, examining various types and their spatial efficiencies. Studies have explored office buildings, mid-rise wooden apartments, and residential structures, highlighting issues such as regulatory challenges and the efficiency of different forms and materials. Research has also investigated service core designs in supertall office buildings, optimal land use for single-family homes, and spatial efficiency in hotels. Trends in spatial optimization have been noted, with the common use of central cores and externally framed systems, although efficiency decreases with height.

Further studies emphasize the impact of prismatic structures, digitalization, lease span, and free-form designs, especially for solar gain in cold regions. Comprehensive analyses cover office tower designs, mixed-use towers, and the unique dynamics of timber construction, aiming to bridge gaps in understanding space efficiency across high-rise buildings.

3. Materials and Methods

As illustrated in Figure 1, the case study method was meticulously employed to systematically compile, classify, and analyze data from 54 contemporary tall building projects in Turkey. This widely utilized research method facilitates the detailed recording of both qualitative and quantitative data and supports comprehensive literature reviews [48,49]. By enabling an in-depth examination of the architectural and structural characteristics of these projects, the case study method allows researchers to delve deeply into real-world examples, providing a robust framework for thorough analysis. This method offers significant insights into the unique design elements and structural aspects of these buildings, thereby enhancing the understanding of modern architectural practices. By concentrating on specific examples, researchers can identify commonalities and differences across the spectrum of Turkish tall building designs, uncovering emerging patterns and trends in contemporary architecture. The method's flexibility allows for the incorporation of diverse data sources, including blueprints, schematics, and other pertinent documents, ensuring a comprehensive and nuanced understanding of each project [50]. This holistic approach not only enriches the research with detailed case-specific insights but also contributes to the broader discourse on architectural and structural innovations in the field of tall buildings.

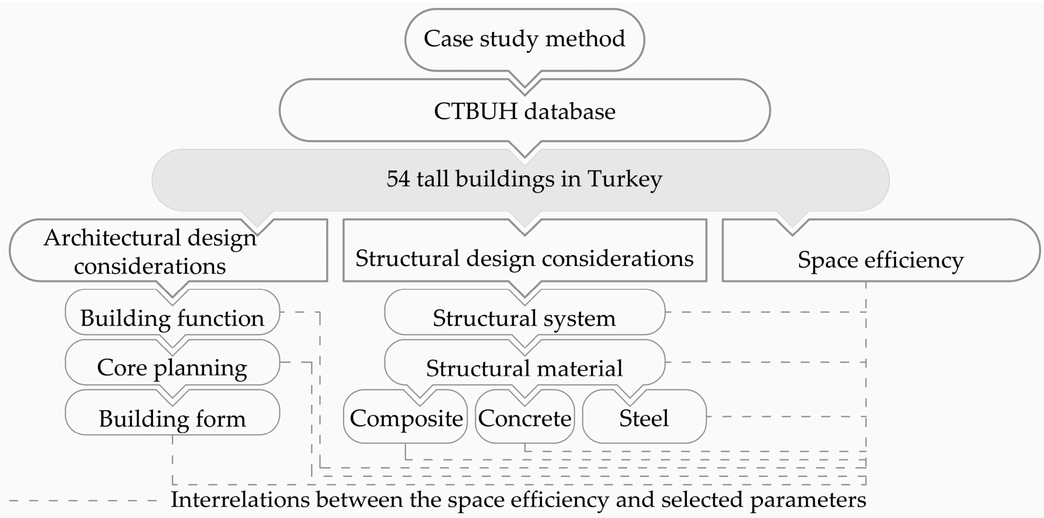

Figure 1. Research method flowchart (created by authors).

According to the classification by the Council on Tall Buildings and Urban Habitat (CTBUH), buildings that reach a minimum of 14 floors or 50 m in height are designated as "tall buildings" [12]. This article adhered to this specific definition, ensuring consistency with established standards in their analysis and discussion. It is important to note that CTBUH is a leading nonprofit organization dedicated to advancing global urban development discussions. CTBUH focuses on fostering sustainable and resilient cities in the face of rapid urbanization and climate change. As an authority in the field, CTBUH determines the heights of tall buildings and awards prestigious titles such as "The World's Tallest Building". Through initiatives like "Buildings of Distinction", it recognizes notable projects that exemplify excellence in design and innovation. Additionally, CTBUH facilitates the exchange of information and provides valuable networking opportunities for urban development professionals worldwide, thereby promoting best practices and collaboration in the industry.

The choice of 54 cases in this paper guarantees sturdy and indicative outcomes, especially considering the natural scarcity of accessible contemporary Turkish high-rise structures. This magnitude of instances permits the detection of notable tendencies and arrangements in spatial usage and architectural characteristics. The assortment among the chosen instances, encompassing diverse locales in Turkey, building elevations, and design types, amplifies the applicability of the discoveries. Notably, this study scrutinizes skyscrapers across Turkey from an extensive assortment of nations, including forty-one from Istanbul, seven from Ankara, and six from Izmir (as portrayed in Figure 2 and elaborated in Table 1). By including such diversity, this research provides a comprehensive outlook on current methodologies in tall building construction in Turkey. From a methodological viewpoint, a sample volume of about 30 case study samples suffices for deriving substantial deductions in the existing literature, balancing the intensity and range of analysis as proven by earlier studies [22,38,41]. Hence, the investigation of 54 instances constitutes a resilient basis for comprehending spatial usage in Turkish tall structures, ensuring the study's insights are credible and broadly applicable, thereby aiding in the recognition of recurring themes such as function, core design, structure, structural system, and various construction materials.

Figure 2. Tall building cases across various cities depicted geographically on map of Turkey (created by authors).

Table 1. Tall buildings in Turkey.

#	Building Name	City	Height (Meters)	# of Stories	Completion Date	Function
1	Skyland Office Tower	Istanbul	284	65	2017	Office
2	Skyland Residance Tower	Istanbul	284	64	2017	Residential
3	Sapphire Tower	Istanbul	261	55	2010	Residential
4	Vakif Bank Headquarters Tower 1	Istanbul	221	43	2023	Offce
5	Nurol Life	Istanbul	220	60	2018	Residential
6	İstanbul Tower 205	Istanbul	220	54	2019	Office
7	İstanbul International Finance Center Ziraat Tower I	Istanbul	219	46	2023	Office
8	Mistral Office Tower	Izmir	216	48	2017	Office
9	Maslak Spine Tower	Istanbul	202	47	2014	M(R+O)
10	Folkart Tower A	Izmir	200	40	2014	M(O+R)
11	Folkart Tower B	Izmir	200	40	2015	M(O+R)
12	Elya Royal Tower	Ankara	195	45	2020	M(R+O)
13	Anthill Residence 1	Istanbul	195	54	2010	Residential

Table 1. *Cont.*

#	Building Name	City	Height (Meters)	# of Stories	Completion Date	Function
14	Anthill Residence 2	Istanbul	195	54	2011	Residential
15	Ciftci Tower A	Istanbul	194	45	2018	Residential
16	Ciftci Tower B	Istanbul	194	45	2018	Residential
17	Istanbul International Finance Center Ziraat Tower II	Istanbul	194	40	2023	Office
18	Point Bornova	Izmir	193	50	2016	M(R+O)
19	Varyap Meridian A Block	Istanbul	188	52	2012	Residential
20	Ege Perla Tower A	Izmir	186	46	2016	Residential
21	Kuzu Effect	Ankara	186	46	2018	M(O+R)
22	Allianz Tower	Istanbul	186	40	2015	Office
23	Varyap Meridian C Block	Istanbul	180	45	2013	Residential
24	Palladium Tower	Istanbul	180	43	2014	Office
25	Skyland Hotel Tower	Istanbul	180	28	2018	Hotel
26	Elmar Towers 1	Ankara	177	47	2020	Residential
27	Akasya Tower	Istanbul	173	55	2014	M(R+O)
28	Ozdilek Plaza Tower A	Istanbul	170	38	2014	M(H+O)
29	Soyak Kristalkule ǀ Finansbank Headquarters	Istanbul	169	32	2014	Office
30	YDA Center	Ankara	166	37	2019	M(R+H+O)
31	Selenium Twins 1	Istanbul	165	34	2010	Residential
32	Selenium Twins 2	Istanbul	165	34	2010	Residential
33	Varyap Meridian E Block	Istanbul	164	41	2012	Residential
34	Portakal Çiçeği Kulesi	Ankara	160	37	2011	Residential
35	Torun Center-East Tower	Istanbul	160	43	2016	Residential
36	Torun Center-South Tower	Istanbul	160	43	2016	Residential
37	Aris Grand Tower	Istanbul	160	41	2019	M(R+O)
38	Sheraton Istanbul Esenyurt Hotel & Residences	Istanbul	158	42	2022	M(R+H)
39	Trump Tower 1	Istanbul	156	39	2011	Residential
40	Four Winds Tower A	Istanbul	156	49	2014	Residential
41	Four Winds Tower B	Istanbul	156	49	2014	Residential
42	Four Winds Tower C	Istanbul	156	49	2014	Residential
43	Four Winds Tower D	Istanbul	156	49	2014	Residential
44	Quasar Residences	Istanbul	156	40	2016	M(R+O)
45	Mistral Residential Tower	Izmir	154	38	2017	Residential
46	Vakif Bank Headquarters Tower 2	Istanbul	152	37	2023	Office
47	İstanbloom	Istanbul	150	46	2015	Residential
48	Türk Telekom Tower	Ankara	150	34	2015	Office
49	Regnum Sky Tower	Ankara	150	30	2016	Office
50	Dumankaya IKON	Istanbul	149	42	2012	M(R+O)
51	42 Maslak Tower 1	Istanbul	148	39	2014	M(R+O)
52	Özdilek Plaza Tower B	Istanbul	148	37	2014	Residential
53	42 Maslak Tower 2	Istanbul	148	39	2015	Residential
54	Trump Tower 2	Istanbul	147	37	2011	Office

Note on abbreviation: 'M' indicates Mixed Use; 'O' indicates Office, 'R' indicates Residential, 'H' indicates Hotel.

The foundational data and documentation necessary for calculating space efficiency were sourced from the official websites of pertinent project stakeholders, including architects, engineers, contractors, and clients. The authors undertook a thorough endeavor to identify and select floor plans, including and redrawing those of low-rise floors, and typical floors, to yield more consistent and precise data for analyzing spatial efficiency across the 54 instances. Furthermore, this careful method of using comparable floor plans as much as possible aims to generate more dependable data for spatial efficiency, considering that, in many tall buildings, the core area diminishes as the structure ascends. On the other hand, structures lacking sufficient details about their load-bearing systems and floor plans were omitted from this compilation.

There is significant interest and utility in drawing as a tool for scientific analysis, particularly within the field of architecture [51]. Drawing serves not merely as a means of documentation but as a powerful analytical tool that bridges the gap between conceptual ideas and their physical realization. By examining original drafts and blueprints through drawing, architects and researchers can gain a comprehensive understanding of a project's historical context, structural solutions, and design intentions. This process involves analyzing various components, such as usage, presentation modes, and graphic techniques, which collectively contribute to the evolution and development of architectural projects. Drawings derived from existing realities are valued not for their documentary quality but as analytical materials that provide in-depth insights into the architectural work. This approach transforms the act of drawing into a cognitive process, where the interplay between the hand and the mind facilitates a deeper understanding and reflection on design decisions, ultimately enriching the architectural discourse and practice.

The profound impact of architectural form on the user's life experience and, consequently, the quality of the final architectural product is worth noting [52]. Form is not merely a physical construct but an abstract, dynamic entity that transcends materiality, imbued with cultural and historical significance. This abstractness allows for a transcendental interpretation, making the form timeless and non-temporal. The design process should embrace this abstract nature of form, ensuring that it resonates with the intellectual, social, and cultural dimensions of human life. By integrating these dimensions, architects can create spaces that are not only functional but also reflective and harmonious, enhancing the user's experience and the overall quality of the architectural product. This holistic approach to form recognizes the importance of both the material and the idea, pushing the boundaries of traditional design to foster environments that are humane and culturally enriched.

Critical architectural and structural considerations affecting space efficiency include the following:

- Core planning, influencing vertical movement and the allocation of shafts;
- Form, dictating the size and configuration of layouts;
- Structural system, determining the sizes and placement of load-bearing elements;
- Structural material, impacting the dimensions of load-bearing components.

In terms of core typology, in this study, and building on the previous literature [53–55], the authors used the classification outlined in Figure 3, which is more detailed and comprehensive [30]. Examples of remarkable tall buildings worldwide that utilize different core arrangements include the following: Burj Khalifa [56] and Shanghai Tower, with central cores [57], 111 West 57th Street [58] and 53 West 53, with peripheral cores [59], and Hanking Center Tower [60] and ADNOC Headquarters, with external cores [61].

Regarding building forms, in contrast to previous research in the field [62,63], the classification system by [31] is considered superior and more comprehensive for categorizing tall structures, including those with unconventional designs. A standard tall building can be segmented into three parts: the top or head, the central body or tower, and the base. This paper primarily classifies building forms based on the configuration of the tower, as shown in Figure 4. Examples of remarkable tall buildings worldwide that utilize different form arrangements include the following: Burj Khalifa, with a setback form [56], Shanghai Tower, with a twisted form [57], 111 West 57th Street, with a setback form [58], 53 West 53, with a tapered form [59], Hanking Center Tower, with a tapered form [60], and ADNOC Headquarters, with a prismatic form [61].

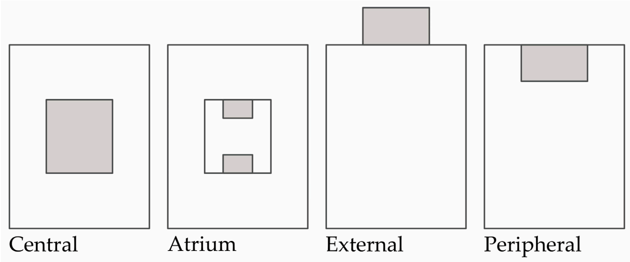

Figure 3. Core classification (created by authors).

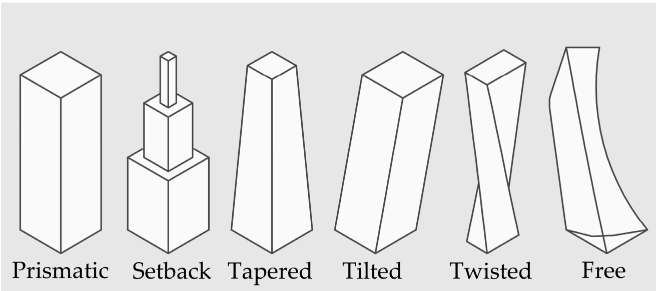

Figure 4. Form classification (created by authors).

For lateral bracing of tall buildings, numerous structural systems and classifications are employed in practice and extensively discussed in the literature [64–71]. However, the terminology used for structural systems in the literature can vary across different sources, despite referring to the same structural system. Additionally, some sources exclude relatively recent structural systems, and there are inconsistencies in the classifications based on structural materials. Within this framework, this research uses the structural system classifications by [32], owing to its more elaborate and exhaustive framework. Diagrams of these structural systems are presented in Figure 5. Examples of remarkable tall buildings worldwide that utilize different structural system arrangements include the following: Burj Khalifa, with a buttressed core system [56], Shanghai Tower [57] and 111 West 57th Street [58], with outriggered frame systems, 53 West 53, with a framed-tube system [59], Hanking Center Tower, with a trussed-tube system [60], and ADNOC Headquarters, with a shear-walled frame system [61].

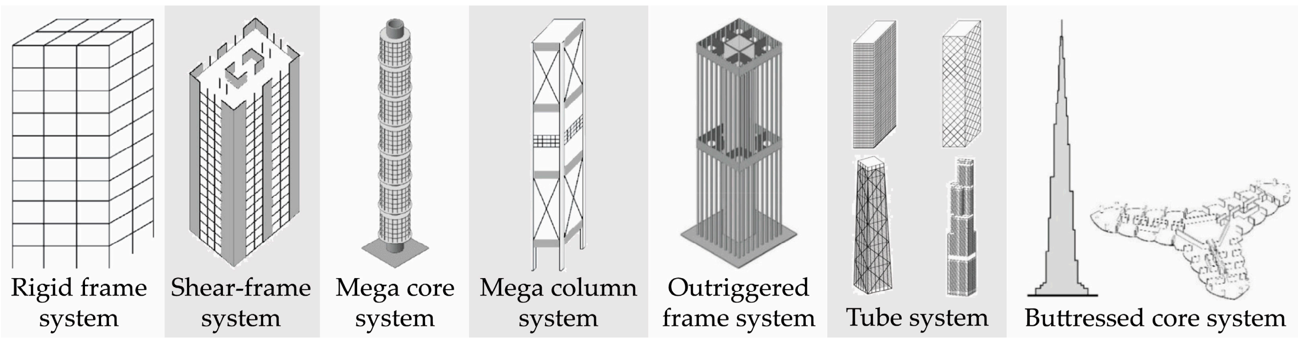

Figure 5. Structural system classification (created by authors).

Given that the choice of structural materials significantly impacts the dimensions of structural components, their selection emerges as a critical factor affecting space utilization efficiency. These materials typically fall under three main categories: steel, (reinforced) concrete, and composite. In this investigation, with a primary focus on vertical load-bearing elements such as shear walls, the term "composite" is employed to describe structures where load-bearing members comprise a blend of concrete, steel, or both.

Space efficiency, delineating the effective deployment of net floor area (NFA) relative to GFA, assumes paramount significance, especially for stakeholders aiming to optimize financial returns by maximizing floor plan utilization. The level of spatial efficiency is heavily contingent upon various factors, including the selection of structural frameworks and architectural planning.

4. Field Work

In this section, the critical parameters of architectural design that influence space efficiency, including functionality, core organization, and form, were examined. Additionally, the key structural parameters such as structural systems and materials were also addressed. The discourse also assessed space efficiency and its interplay with various design parameters.

4.1. Function, Core Planning and Building Form

A comprehensive analysis was conducted within the scope of examining the functions of Turkish tall buildings. This analysis predominantly revealed that, within the sample, 48%, represented by 26 towers, have residential functions, 26%, or 14 towers, have mixed-use functions, 24%, or 13 towers, serve as office buildings, and, finally, the smallest share is occupied by hotel functions with one building, as shown in Figure 6 and elaborated in Table 2.

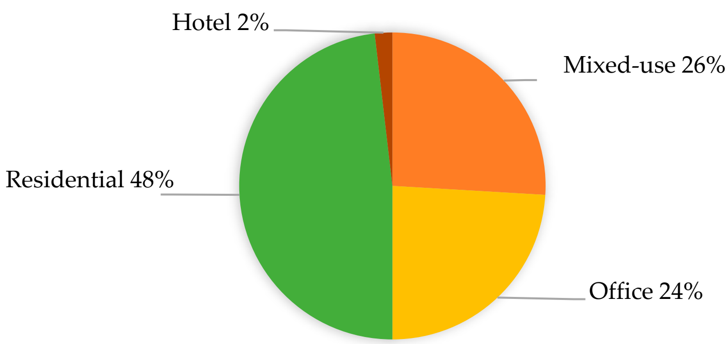

Figure 6. Case studies by function.

Table 2. Tall buildings by form, core type, structural system, and material in Turkey.

#	Building Name	Building Form	Core Type	Structural System	Structural Material
1	Skyland Office Tower	Tapered	Central	Outriggered frame	Reinforced Concrete
2	Skyland Residance Tower	Tapered	Central	Shear walled frame	Reinforced Concrete
3	Sapphire Tower	Prismatic	Peripheral	Shear walled frame	Reinforced Concrete
4	Vakif Bank Headquarters Tower 1	Twisted	Central	Outriggered frame	Reinforced Concrete
5	Nurol Life	Prismatic	Central	Shear walled frame	Reinforced Concrete
6	İstanbul Tower 205	Prismatic	Central	Outriggered frame	Composite
7	İstanbul International Finance Center Ziraat Tower I	Prismatic	Central	Outriggered frame	Composite
8	Mistral Office Tower	Twisted	Central	Shear walled frame	Reinforced Concrete
9	Maslak Spine Tower	Prismatic	Central	Shear walled frame	Reinforced Concrete
10	Folkart Tower A	Free	Peripheral	Shear walled frame	Reinforced Concrete
11	Folkart Tower B	Free	Peripheral	Shear walled frame	Reinforced Concrete
12	Elya Royal Tower	Prismatic	Central	Shear walled frame	Reinforced Concrete

Table 2. *Cont.*

#	Building Name	Building Form	Core Type	Structural System	Structural Material
13	Anthill Residence 1	Setback	Peripheral	Shear walled frame	Reinforced Concrete
14	Anthill Residence 2	Setback	Peripheral	Shear walled frame	Reinforced Concrete
15	Ciftci Tower A	Prismatic	Central	Outriggered frame	Composite
16	Ciftci Tower B	Prismatic	Central	Outriggered frame	Composite
17	Istanbul International Finance Center Ziraat TowerII	Prismatic	Central	Outriggered frame	Composite
18	Point Bornova	Prismatic	Central	Shear walled frame	Composite
19	Varyap Meridian A Block	Free	Central	Shear walled frame	Reinforced Concrete
20	Ege Perla Tower A	Prismatic	Central	Shear walled frame	Reinforced Concrete
21	Kuzu Effect	Prismatic	Central	Shear walled frame	Reinforced Concrete
22	Allianz Tower	Tapered	Central	Outriggered frame	Reinforced Concrete
23	Varyap Meridian C Block	Free	Peripheral	Shear walled frame	Reinforced Concrete
24	Palladium Tower	Prismatic	Central	Shear walled frame	Reinforced Concrete
25	Skyland Hotel Tower	Tapered	Central	Shear walled frame	Reinforced Concrete
26	Elmar Towers 1	Setback	Central	Shear walled frame	Reinforced Concrete
27	Akasya Tower	Prismatic	Central	Outriggered frame	Reinforced Concrete
28	Ozdilek Plaza Tower A	Prismatic	Central	Shear walled frame	Reinforced Concrete
29	Soyak Kristalkule | Finansbank Headquarters	Free	Central	Shear walled frame	Reinforced Concrete
30	YDA Center	Free	Peripheral	Shear walled frame	Reinforced Concrete
31	Selenium Twins 1	Prismatic	Peripheral	Shear walled frame	Reinforced Concrete
32	Selenium Twins 2	Prismatic	Peripheral	Shear walled frame	Reinforced Concrete
33	Varyap Meridian E Block	Free	Peripheral	Shear walled frame	Reinforced Concrete
34	Portakal Çiçeği Kulesi	Prismatic	Central	Shear walled frame	Reinforced Concrete
35	Torun Center-East Tower	Setback	Peripheral	Shear walled frame	Reinforced Concrete
36	Torun Center-South Tower	Setback	Peripheral	Shear walled frame	Reinforced Concrete
37	Aris Grand Tower	Setback	Peripheral	Shear walled frame	Reinforced Concrete
38	Sheraton Istanbul Esenyurt Hotel & Residences	Prismatic	Central	Shear walled frame	Reinforced Concrete
39	Trump Tower 1	Tapered	Central	Shear walled frame	Reinforced Concrete
40	Four Winds Tower A	Prismatic	Peripheral	Shear walled frame	Reinforced Concrete
41	Four Winds Tower B	Prismatic	Peripheral	Shear walled frame	Reinforced Concrete
42	Four Winds Tower C	Prismatic	Peripheral	Shear walled frame	Reinforced Concrete
43	Four Winds Tower D	Prismatic	Peripheral	Shear walled frame	Reinforced Concrete
44	Quasar Residences	Setback	Peripheral	Shear walled frame	Reinforced Concrete
45	Mistral Residential Tower	Twisted	Central	Shear walled frame	Reinforced Concrete
46	Vakif Bank Headquarters Tower 2	Twisted	Central	Outriggered frame	Reinforced Concrete
47	İstanbloom	Free	Central	Shear walled frame	Reinforced Concrete
48	Türk Telekom Tower	Prismatic	Peripheral	Shear walled frame	Reinforced Concrete
49	Regnum Sky Tower	Setback	Central	Shear walled frame	Reinforced Concrete
50	Dumankaya IKON	Prismatic	Central	Shear walled frame	Reinforced Concrete
51	42 Maslak Tower 1	Prismatic	Central	Shear walled frame	Reinforced Concrete
52	Özdilek Plaza Tower B	Prismatic	Central	Shear walled frame	Reinforced Concrete
53	42 Maslak Tower 2	Prismatic	Central	Shear walled frame	Reinforced Concrete
54	Trump Tower 2	Tapered	Central	Shear walled frame	Reinforced Concrete

Figure 7 and Table 2 illustrate that the central core was predominantly utilized, accounting for a usage rate of 65%. This preference can be attributed to its compact nature, pivotal role within the structural framework, potential to enhance flexibility in façade arrangement, and contribution to fire safety. These combined factors render it the most feasible choice among core arrangements. Furthermore, the absence of external core configurations and the lesser utilization of peripheral core typologies may stem from their less advantageous characteristics, such as longer fire escape distances and less efficient circulation routes. Additionally, the lack of an atrium core arrangement may be linked to the heightened demand for enhanced fire safety measures.

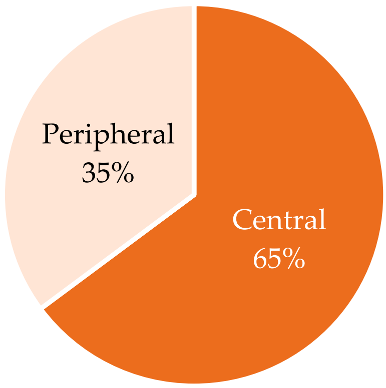

Figure 7. Case studies by core type.

Figure 8 and Table 2 show that prismatic shapes were predominantly used, with a usage rate exceeding 50%. These shapes in construction offer a versatile and efficient method, combining strength, aesthetic adaptability, and eco-friendliness. Their geometric simplicity allows for better load distribution, leading to more efficient and economical structural designs. Furthermore, prismatic forms facilitate modular construction, speeding up the building process. Their flat surfaces provide ample options for various façade treatments, enabling a modern and customizable look. Environmentally, prismatic shapes reduce material waste and enhance energy efficiency with optimal insulation, effective daylighting, and natural ventilation.

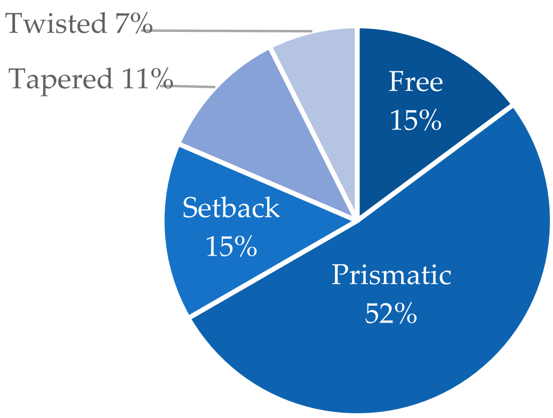

Figure 8. Case studies by building form.

Table 3 contrasts the results on main architectural parameters with those of Middle Eastern [43] and Asian skyscrapers [44].

Table 3. Comparison of function, core planning, and form.

	The Findings	Middle Eastern Skyscrapers (27 Cases)	Asian Skyscrapers (75 Cases)
Function	**Residential (48%)** Office (24%) Hotel (2%) Mixed-use (26%)	**Residential (45%)** Office (22%) Mixed-use (33%)	Residential (5%) Office (38%) **Mixed-use (57%)**
Core type	**Central (65%)** Peripheral (35%)	**Central (96%)** External (4%)	**Central (99%)** External (1%)
Form	**Prismatic (52%)** Setback (15%) Tapered (11%) Twisted (7%) Free (15%)	**Prismatic (45%)** Setback (7%) Tapered (7%) Twisted (4%) Free (37%)	Prismatic (23%) Setback (13%) **Tapered (36%)** Twisted (1%) Free (27%)

4.2. Structural Material and Structural System

Concrete has become the predominant structural material, accounting for almost 90% of usage in the construction of tall buildings in Turkey, as shown in Figure 9 below and as elaborated in Table 2. Several factors contribute to concrete dominance. Its cost-effectiveness in Turkey makes it economically favorable for large-scale projects. Additionally, its ease of use in both construction and building processes allows for efficient on-site implementation. Concrete's inherent fire-resistant properties enhance safety standards in tall structures, and its superior ability to reduce sway caused by wind, surpassing that of steel alternatives, improves structural stability and occupant comfort. This widespread adoption of concrete highlights its versatility and suitability for meeting the demanding requirements of tall building construction in Turkey.

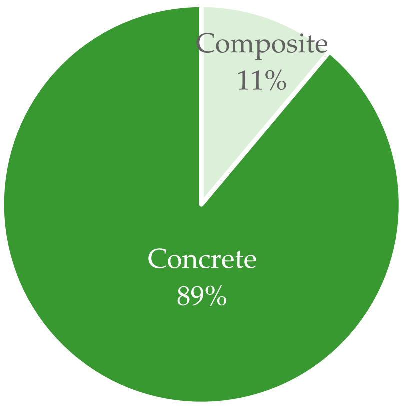

Figure 9. Cases by structural material.

In a comprehensive examination encompassing 54 cases, as depicted in Figure 10, and as elaborated in Table 2, the utilization of shear-walled frame systems occurred as the predominant structural system, constituting over 80%. These systems ingeniously address the limitations inherent in both rigid frames and shear walls by amalgamating these structural elements. Within these systems, the frame provides supplementary support to the shear wall at elevated levels, concurrently augmenting the stability of the frame at lower levels. Consequently, such integrated systems exhibit heightened resilience against lateral forces, achieving a superior degree of rigidity in contrast to structures that rely solely on either a shear wall or a rigid frame system. Prominent edifices such as the Zorlu Center and the Sapphire Tower exemplify this approach.

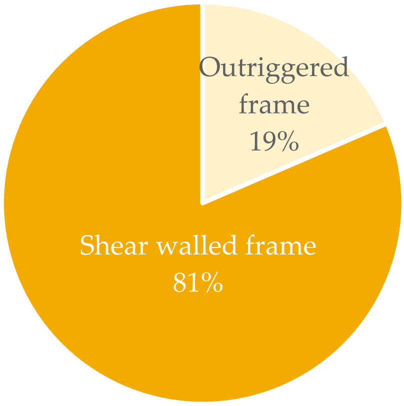

Figure 10. Cases by structural system.

Table 4 contrasts the results on main structural parameters with those of Middle Eastern [43] and Asian skyscrapers [44].

Table 4. Comparison of structural material and system.

	The Findings	**Middle Eastern Skyscrapers (27 Cases)**	**Asian Skyscrapers (75 Cases)**
Structural material	**Concrete (89%)** Composite (11%)	**Concrete (70%)** Composite (30%)	Concrete (18%) **Composite (79%)** Steel (3%)
Structural system	Outriggered frame (19%) **Shear-walled frame (81%)**	**Outriggered frame (44%)** Tube (26%) Buttressed core (4%) Mega column & core (15%) Shear-frame (11%)	**Outriggered frame (76%)** Tube (17%) Buttressed core (3%) Mega column & core (3%) Shear-frame (1%)

4.3. Space Efficiency

In this article, an analysis of 54 instances revealed that the average space efficiency stood at 78%, with the average ratio of core area to GFA reaching 19%. These metrics exhibited a range from a minimum of 64% for space efficiency and 9% for the core area to GFA ratio, to a maximum of 86% and 34%, respectively, as demonstrated in Figure 11.

Table 5 compares the findings on the average space efficiency and the ratio of core-to-GFA to those of Middle Eastern [43] and Asian skyscrapers [44].

Table 5. Comparison of average space efficiency and ratio of core-to-GFA.

	The Findings	**Middle Eastern Skyscrapers (27 Cases)**	**Asian Skyscrapers (75 Cases)**
Average space efficiency	78% (max. 86%, min. 64%)	75.50% (max. 84%, min. 63%)	67.50% (max. 82%, min. 56%)
Average ratio of core-to-GFA	19% (max. 34%, min. 9%)	21.30% (max. 36%, min. 11%)	29.50% (max. 38%, min. 14%)

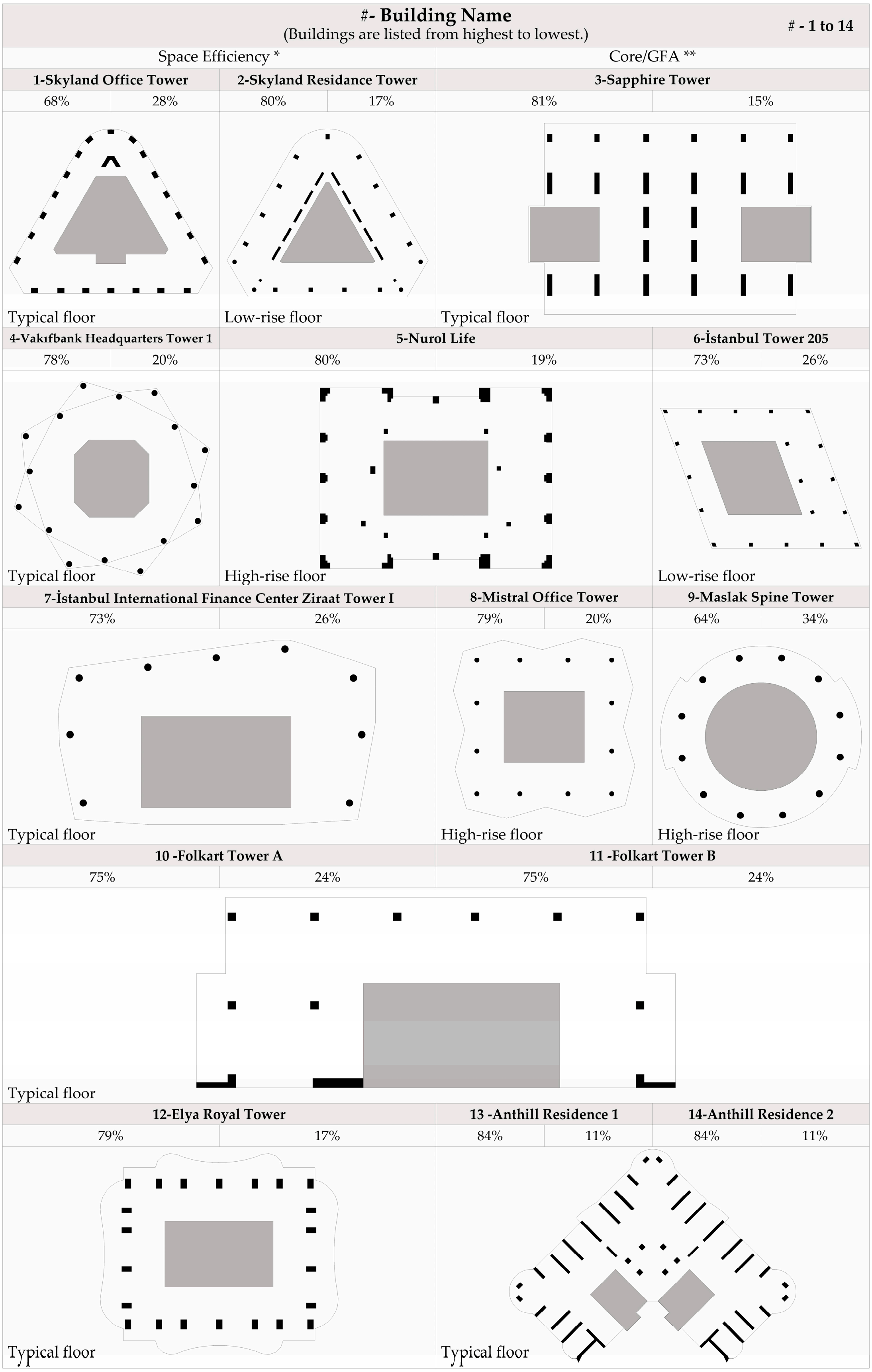

Figure 11. *Cont.*

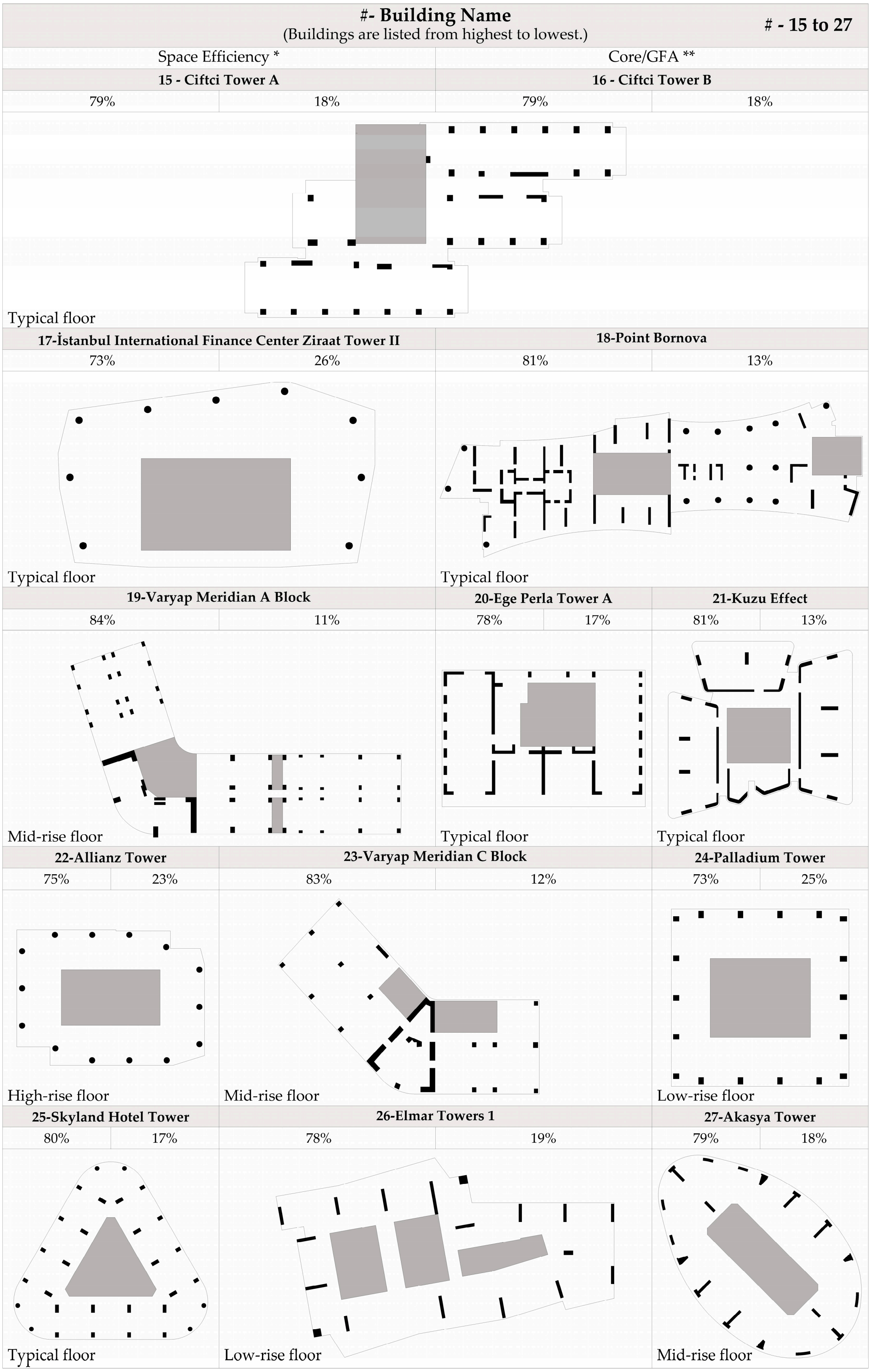

Figure 11. *Cont*.

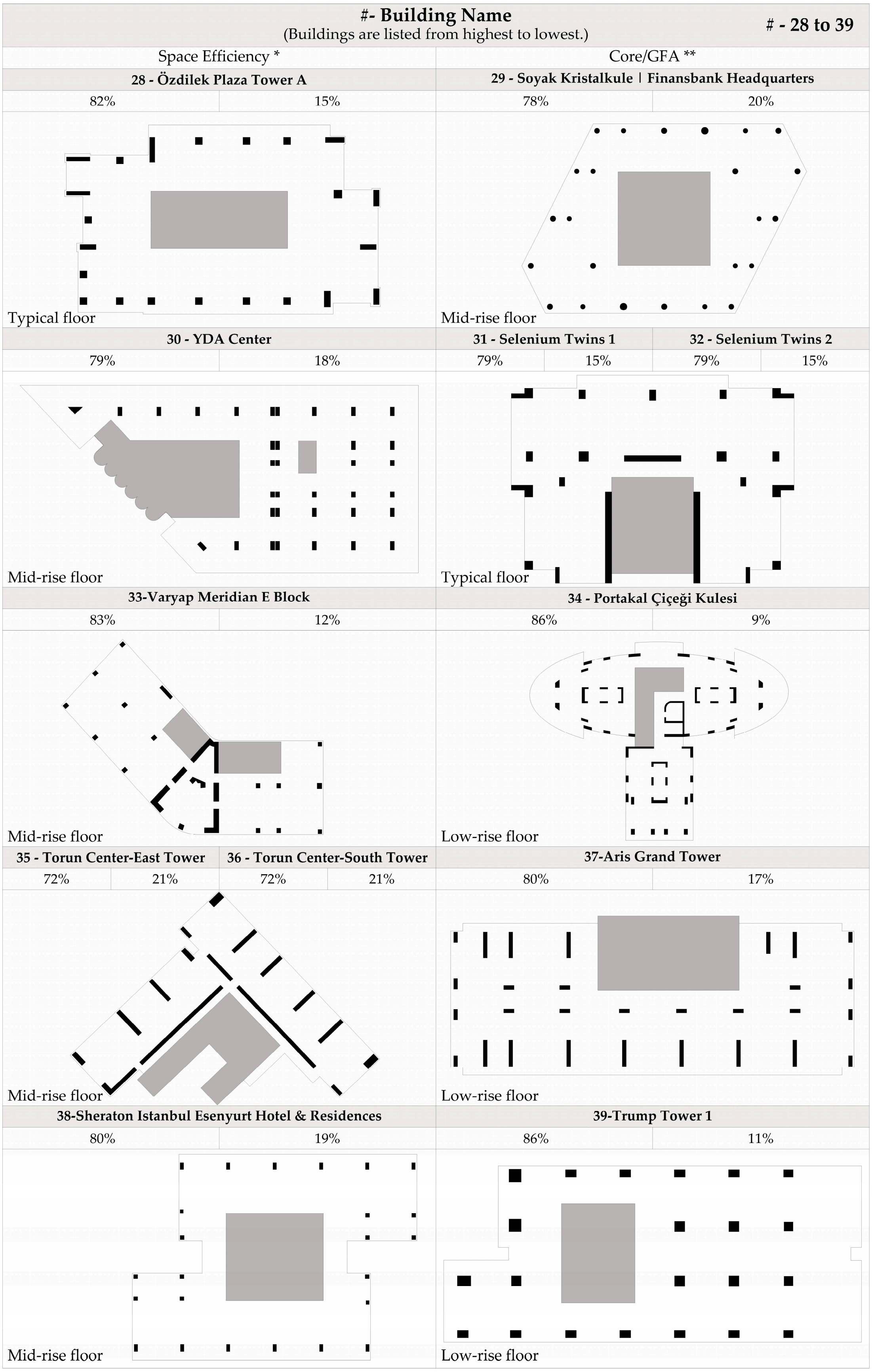

Figure 11. *Cont.*

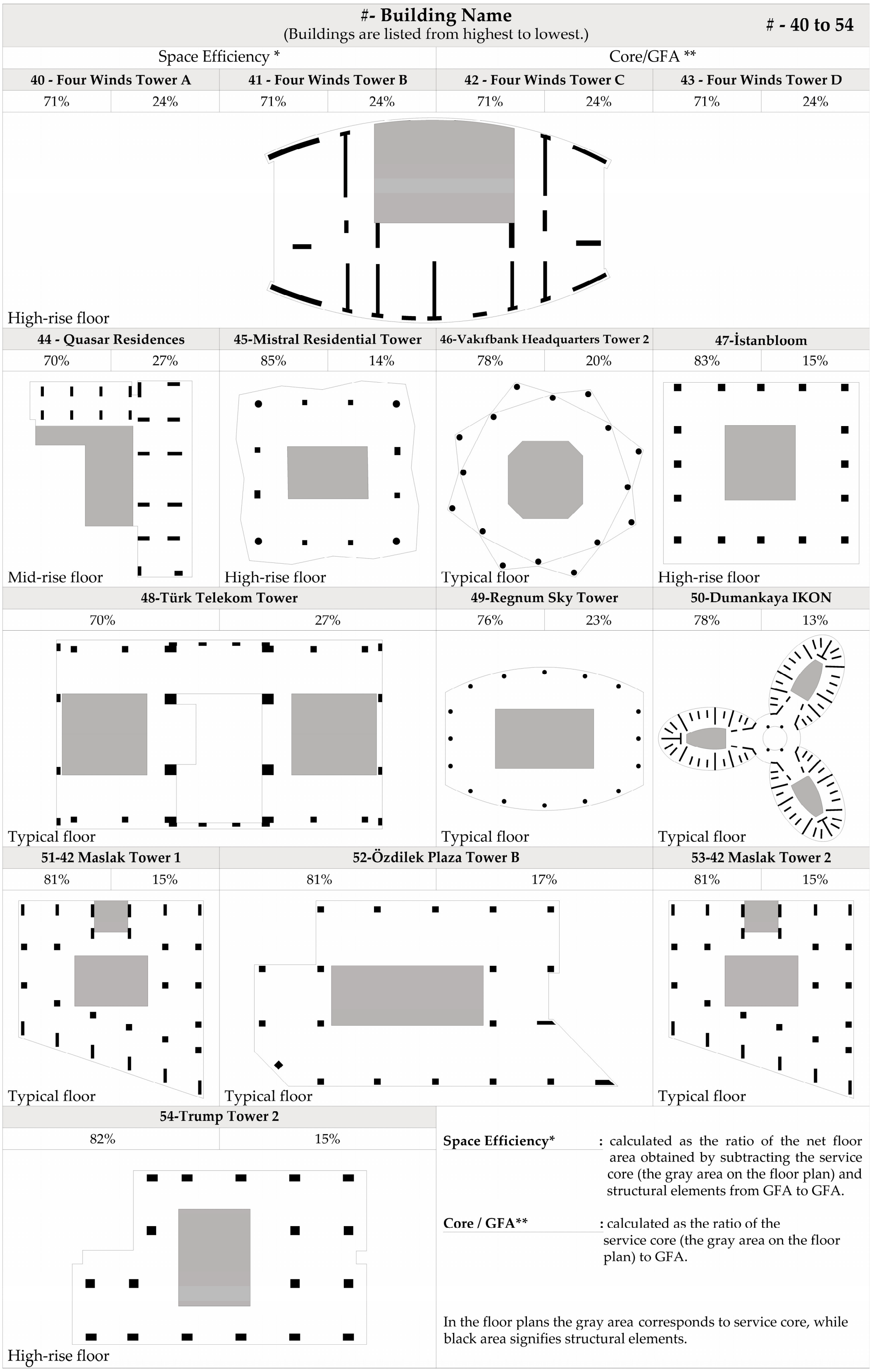

Figure 11. Space efficiency and core/GFA of Turkish tall buildings.

Portakal Çiçeği Kulesi, Trump Tower 1, Mistral Residential Tower, and Varyap Meridian A Block showcase exceptional progress in space use and architectural design, achieving impressive spatial efficiencies of between 84% and 86%. These buildings set a new standard, with the smallest core-to-GFA ratio within the study group, as detailed in Figure 11. This outstanding performance stems from precisely designed cores that emphasize compactness by optimizing service areas and shaft arrangements, thereby maximizing usable floor area. Additionally, these towers utilize a shear-walled frame system, which bolsters their strength against both vertical and horizontal forces by using compact cross-sections of structural elements to effectively distribute and resist loads. This integration of cutting-edge design principles not only ensures superior space efficiency but also enhances the structural robustness of these buildings, establishing a new benchmark for sustainable urban design.

Relation of Space Efficiency and Function, Core Typology, form, Structural System, and Material

In Figures 12–16, empirical data elucidate the relationship between spatial efficiency and the corresponding architectural and structural design considerations. The graphical representation employs bars on the right-hand side to illustrate the total number of cases categorized by related classifications. Colored dots show the spatial efficiency of structures corresponding to their respective considerations. Furthermore, the gray bar denotes the prevalence of structures within the sampled population that share identical considerations.

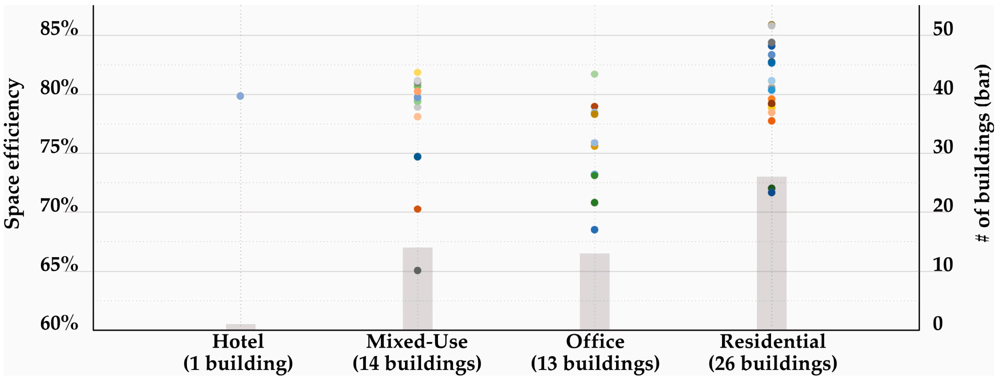

Figure 12. Cases by function.

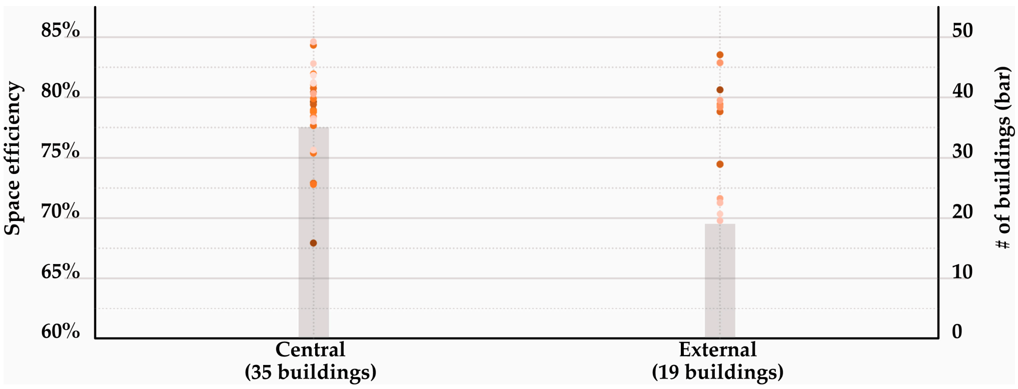

Figure 13. Space efficiency by core type.

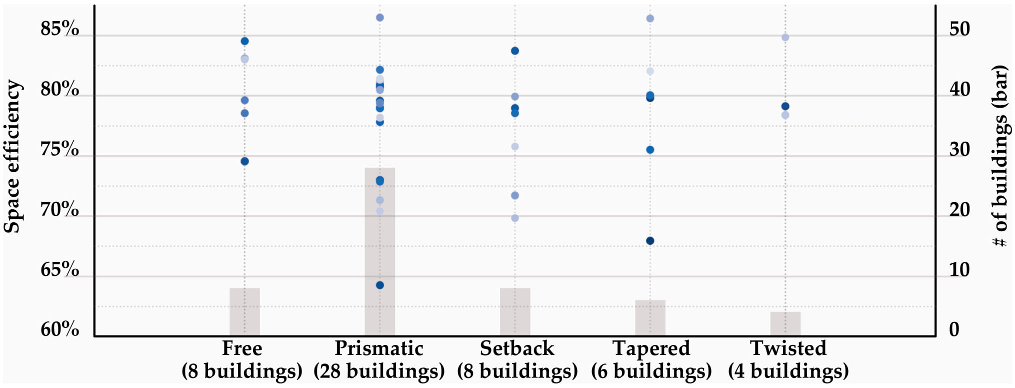

Figure 14. Space efficiency by form.

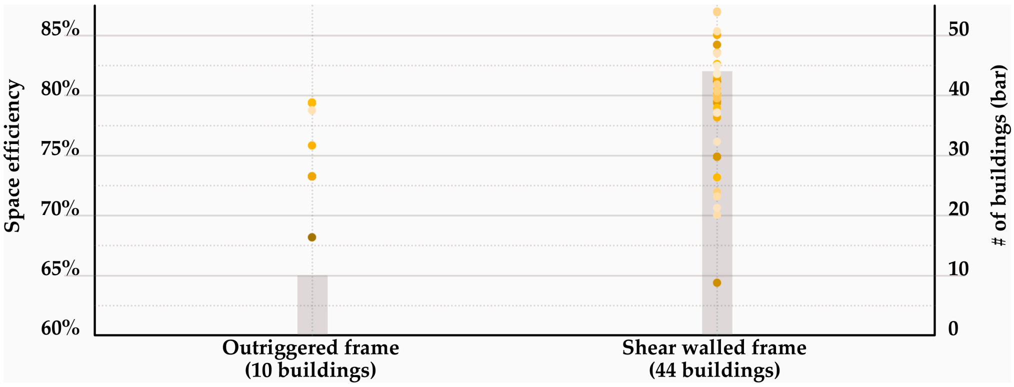

Figure 15. Space efficiency by structural system.

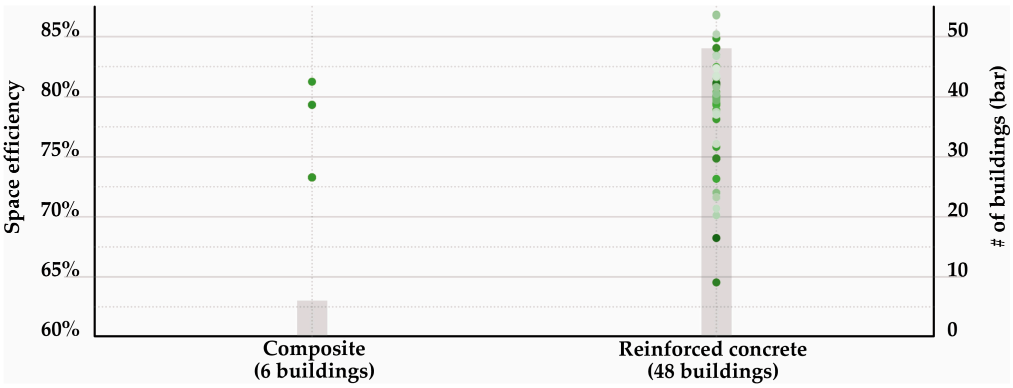

Figure 16. Space efficiency by structural material.

As seen in Figure 12, the average spatial efficiencies of 54 buildings examined are as follows: 79% for 26 residential, 77% for 14 mixed-use, and 75% for 13 office buildings. The presence of only one hotel precluded the calculation of an average for this category. The efficiencies range between 71% and 86% for residential, 64% and 82% for mixed-use, and 68% and 82% for towers.

As shown in Figure 13, the central core type occurred as the prevalent selection, encompassing 35 buildings within the dataset. These structures showcased spatial efficiency levels ranging from 64% to 86%, with an average efficiency of 79%. Peripheral type, comprising 19 buildings, demonstrated spatial efficiency levels ranging from 70% to 84%, averaging at 76%. Consequently, an average spatial efficiency disparity of 3% is observed between the two core typologies.

As illustrated in Figure 14, prismatic configurations emerged as the prevailing choice, observed in 28 instances. These configurations have exhibited spatial efficiency ratios ranging from 64% to 86%, with an average of 77%. In contrast, instances featuring free, setback, tapered, and twisted forms collectively total 26 cases.

As shown in Figure 15, shear-walled frame systems emerged as the predominant structural system, with 44 occurrences. These configurations demonstrated space efficiency levels ranging from 64% to 86%, with an average of 78%. In contrast, structures employing an outriggered frame system, totaling 10 instances, have exhibited an average space efficiency of 76%.

As depicted in Figure 16, concrete was the primary structural material utilized. This material's spatial efficiency varies between 64% and 86%, with an average efficiency of 78%.

5. Analysis of Results

The literature review identified the central core typology as a widely adopted configuration in tall structures due to its effectiveness in organizing vertical circulation and service elements (e.g., [30,32]). This aligns with the findings, which confirm the prevalence of central core typologies in core arrangements. The widespread use of this typology is attributed to its ability to provide structural stability and efficient spatial organization, supporting the conclusions of previous studies [72–74]. Similarly, several pieces of research on mid-rise and tall buildings highlight prismatic forms as the most common geometric configuration, owing to their simplicity and structural benefits (e.g., [24,31]). The findings confirm this trend, showing that prismatic forms remain prevalent in tall architectural design. This enduring preference underscores the form's effectiveness in optimizing structural performance and spatial efficiency.

Contrary to the findings for Asian towers [44], which predominantly utilize composite construction [75–79], the analysis of favored structural materials in Turkish tall towers revealed a preference for concrete, aligning with trends observed in Middle Eastern skyscrapers [43]. This choice reflects the material's superior performance in seismic regions, offering enhanced rigidity and cost efficiency. Furthermore, while both Asian and Middle Eastern skyscrapers often employ outrigger frame systems to optimize lateral stability and load distribution [80–83], Turkish tall buildings more commonly incorporate shear-walled frame configurations. This preference underscores the adaptation to local seismic codes [84] and construction practices, highlighting the regional engineering strategies tailored to address Turkey's unique geological challenges.

A suggested standard for space usage in tall buildings aims for 75% utilization [85], which is strongly backed by data from various regions and types of buildings. Research on Middle Eastern skyscrapers [43] showed greater space efficiency, with an average of 76% and a range of from 63% to 84%, while the core area to GFA ratio averages 21%, ranging from 11% to 36%. In comparison, Asian skyscrapers [44] revealed a lower average spatial efficiency of 67.5%, with a range between 56% and 82%, and a core area to GFA ratio averaging 29.5%, with variations from 14% to 38%. The extensive analysis of 54 Turkish cases somewhat supported the results for Middle Eastern skyscrapers, showing an average spatial efficiency of 78%, with a range from 64% to 86%, which aligns with historical data, indicating that high-efficiency levels are achievable despite some variability. Similarly, the core area to GFA ratio of 19%, ranging from 9% to 34%, serves as a benchmark for evaluating core space utilization. These varied yet consistent data suggest that a 75% utilization benchmark is not only achievable but also represents best practices in the design and construction of tall towers, offering a scientifically grounded target for optimizing space usage in these buildings.

It is worth noting that, in today's architectural landscape, the prevalence of towering structures, particularly supertall towers exceeding 300 m in height, has become a defining feature in Asia and the Middle East. This architectural trend is intricately linked to the rapid pace of urbanization and robust economic growth [43]. Consequently, it is essential to conduct comparative analyses between skyscraper developments in these regions and pertinent cases in Turkey. Moreover, the selection and quantity of case studies were shaped by multiple influential factors. Firstly, Asia's status as the global leader in skyscraper construction contrasts with the Middle East's rising prominence, albeit with a relatively smaller number of skyscrapers. Secondly, the challenge of accessing comprehensive information on skyscrapers worldwide posed a significant consideration. These elements collectively informed the decision-making process regarding both the number of case studies conducted and the specific examples included. This strategic approach ensured a nuanced exploration of skyscraper architecture within diverse regional contexts.

To enhance urban planning and urban design policy in Turkey, particularly in metropolitan areas such as Istanbul, Ankara, and Izmir, it is imperative to adopt a multifaceted approach that emphasizes space efficiency, structural integrity, and sustainable growth. Policymakers should mandate comprehensive space efficiency studies as a prerequisite for the approval of new high-rise projects, ensuring that the average space efficiency does not fall below the identified 78% benchmark. Additionally, integrating concrete and shear-walled frame systems should be encouraged for their proven efficacy in the current architectural landscape. Urban planners must also prioritize interdisciplinary collaboration, incorporating advancements in facade technology, vertical circulation, and fire safety to address the unique challenges posed by tall buildings. To support this, local governments could establish innovation hubs and workshops that bring together architects, engineers, and technologists. Furthermore, incentives should be provided for designs that optimize the core-to-gross-floor-area ratio, promoting configurations that minimize the core footprint while maximizing usable space. Finally, urban design policies should enforce stringent regulations on the environmental impact of tall buildings, incorporating green building standards to ensure that the expansion of construction zones aligns with sustainable development goals.

Even though sustainable planning factors were omitted due to data constraints, this research highlights the crucial importance of spatial efficiency in boosting financial gains, occupant health, and ecological sustainability in high-rise urban settings. Given the extensive nature of concepts such as circulation flow, spatial flexibility, and adaptability, which warrant separate research endeavors, this article intentionally excludes them. Additionally, this study's specific focus led to the assessment of core areas, omitting the floor area dimensions of the towers and structural elements like columns. The limited access to information on tall buildings and the absence of data, like inter-story heights and floor plan depths for many skyscrapers, further restricted analyses of these properties.

Future research could focus on further enhancing the sustainability and efficiency of tall buildings in Turkey. Studies on the use of innovative materials with low carbon footprints and the integration of energy-efficient systems would be particularly valuable. The application of smart building technologies and green roof systems can contribute to sustainability goals by reducing energy consumption.

6. Conclusions

This study focuses on the space efficiency of tall towers across Turkey, addressing a gap in earlier studies. Through meticulous examination of data from 54 buildings via detailed case studies, the authors pinpointed key determinants influencing spatial efficiency. These elements encompass the configuration and dimensions of the service cores, load-bearing elements, functionality, form, and selection of structural materials. The main conclusions from this study can be summarized as follows:

- Residential use, central core, and prismatic forms are the most prevalent architectural preferences;
- The most preferred structural material and system are concrete and shear-walled frame systems, respectively;
- The average space efficiency and the percentage of core-to-GFA were 78% and 19%, respectively, with measurement ranges varying from a minimum of 64% and 9% to a maximum of 86% and 34%.

With an average spatial efficiency of 78% and a core-to-GFA ratio of 19%, architectural designers now possess well-defined benchmarks for optimizing rentable space and formulating efficient architectural layouts in the Turkish context. By adhering to these guidelines, professionals in the field can create tall structures that are not only more efficient and sustainable but also economically viable. This balance encourages the development of distinctive tall towers that embody contemporary design philosophies and a commitment to environmental sustainability. Additionally, while there are no significant differences between various building groups and an inadequate number of towers in specific categories, such as tapered forms, to make definitive scientific conclusions, it is observed that concrete buildings incorporating centrally designed cores, prismatic designs, and shear-walled frame systems exhibited superior space utilization within the analyzed case study sample. This finding suggests that such architectural strategies may enhance spatial efficiency in future developments in the Turkish tall-building construction industry.

These findings align closely with global trends, where materials such as concrete and shear-walled frame systems are commonly favored due to their superior strength, durability, and cost-efficiency. However, the average space efficiency and core-to-GFA ratios suggest a distinctive approach in Turkish architectural practice. When compared to international benchmarks, these efficiency metrics reveal that Turkish high-rise buildings generally make effective use of available space. Nevertheless, there remains significant potential for improvement, especially in optimizing core design and vertical circulation systems to enhance overall functionality and occupant experience. This indicates that, while Turkish tall buildings are largely in step with global practices, they could benefit from more refined design strategies to maximize spatial efficiency and operational effectiveness.

Author Contributions: Conceptualization, Ö.N.A.; methodology, Ö.N.A. and H.E.I.; software, Ö.N.A.; formal analysis, Ö.N.A. and H.E.I.; investigation, Ö.N.A. and H.E.I.; writing—original draft preparation, Ö.N.A.; writing—review and editing, Ö.N.A. and H.E.I.; supervision, H.E.I. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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

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