The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/2398-4708.htm

An analysis of space efficiency in Asian supertall towers

Hüseyin Emre Ilgın
School of Architecture, Tampere University, Tampere, Finland

Received 21 June 2023
Revised 4 August 2023
8 October 2023
Accepted 15 October 2023

Abstract

Purpose – Supertall towers (300 m+) offer a viable solution to the increasing demand for housing and commercial space caused by rapid urban growth, migration from rural to urban areas and economic expansion in Asia. In this particular context, the efficient utilization of space becomes a crucial factor in the design process for Asian skyscrapers as they seek to address the changing socioeconomic landscape. This study will provide valuable guidance, especially to architectural and structural designers in the pursuit of sustainable development for Asian skyscrapers by analyzing space efficiency.

Design/methodology/approach – The methodology employed in this paper involved a case study approach to gather data on 75 Asian supertall towers in order to examine space efficiency.

Findings – Findings of the research can be summarized as follows: (1) the average space efficiency of these towers was 67.5%, ranging from a minimum of 55% to a maximum of 82%; (2) the average proportion of the core area to the gross floor area (GFA) was 29.5%, with values ranging from 14% to 38%; (3) the majority of Asian skyscrapers exhibited a tapered form and adopted a central core typology, which catered to mixed-use and office purposes; (4) the most frequently utilized structural system was a combination of composite and outriggered frames; (5) space efficiency tended to decrease as the height of the tower increased; and (6) there was no noteworthy difference in the impact of various load-bearing systems and building forms on space efficiency.

Originality/value – There is a noticeable lack of extensive research into space efficiency in supertall towers in Asia, which serves as a hub for skyscrapers. This study seeks to fill this substantial gap in the current scientific literature.

Keywords Space efficiency, Asia, Supertall tower, Architectural and structural design considerations

Paper type Research paper

1. Introduction

In recent times, the proliferation of tall buildings has become the prevailing architectural form in Asia and Middle Eastern nations, thanks to urban development and rapid economic progress (Ilgın, 2022). Furthermore, there has been a significant increase in the height of tall buildings in recent decades, leading to the introduction of a new category known as supertall buildings (300 m+) (Ilgın, 2023a). The development of skyscrapers continues to thrive, particularly in Asia, on an unprecedented scale, establishing the region as one of the most active hubs for skyscraper construction (Moon, 2015).

In the early 20th century, only a limited number of tall buildings, like the Bank of China in Shanghai and the Hong Kong and Shanghai Bank in Hong Kong, were constructed in Asia (Binder, 2001). The emergence of major Asian tall buildings occurred during the late 1960s and early 1970s. Many of these towers followed the prevalent International Style, including the Kasumigaseki Building of 1968 and the Shinjuku Mitsui Building of 1974 in Tokyo, and the Jardine House of 1973 in Hong Kong. Subsequently, there has been a steady increase in tall building developments across Asian countries, especially in densely populated major cities.

Today, metropolises in Asia, including Hong Kong, Shenzhen and Shanghai, have become prominent centers for skyscrapers globally (CTBUH, 2023). Among them, Chinese cities,

© Hüseyin Emre Ilgın. Published by Emerald Publishing Limited. This article is published under the Creative Commons Attribution (CC BY 4.0) licence. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial and non-commercial purposes), subject to full attribution to the original publication and authors. The full terms of this licence may be seen at http://creativecommons.org/licences/by/4.0/legalcode

in particular, hold a significant position on the list of cities with the highest number of skyscrapers. This development can be attributed to China's rapid economic growth over the past few decades, resulting in accelerated urbanization and the construction of numerous skyscrapers. The country has demonstrated a bold approach to urban planning and development, leading to an impressive concentration of skyscrapers in its most dynamic urban centers. Hong Kong stands out in particular, boasting an impressive count of more than 650 tall buildings, including six supertalls. It undoubtedly leads the world in terms of skyscrapers. Hong Kong's unique urban landscape is characterized by its high urban density and status as an international financial center. Iconic buildings such as the ICC Tower, Two International Finance Centre and the Central Plaza have played a crucial role in shaping the city's distinctive vertical paradise.

The demand for residential and commercial spaces in Asian countries continues to pose challenges due to rapid urban growth, significant rural–urban migration and remarkable economic expansion, as observed in the rapid development of Chinese cities (Wang *et al.*, 2020). Unless alternative solutions are discovered to create efficient architectural spaces, the construction of skyscrapers appears to be the inevitable solution for the future of these countries (Al-Kodmany and Ali, 2012). The issue of space efficiency becomes crucial, particularly for supertall towers in Asia, as they strive to address socio-economic changes and provide satisfactory architectural and engineering solutions. Space efficiency plays an important role in meeting the value and investment cost of skyscrapers (Kim and Elnimeiri, 2004).

There is a significant dearth of comprehensive studies regarding the space utilization in supertall buildings in Asia, particularly in regions renowned for their skyscrapers. This research addresses this significant topic by conducting a detailed analysis of 75 case studies. The primary focus of this study is to examine the key architectural and structural planning parameters related to space efficiency. The paper presents critical analyses, which encompass the building's function, form, core typology, load-bearing system and material, along with their interrelation with space efficiency. While sustainable planning considerations, such as energy consumption, were not included due to insufficient data for all towers, the research primarily concentrates on space efficiency. The findings of this study are expected to guide the sustainable development of Asian skyscrapers, particularly within the disciplines of architectural and structural design.

Based on the CTBUH database (CTBUH, 2023), in this research, buildings with a height of 14 storeys or 50 meters are classified as "tall buildings," while buildings exceeding 300 meters and 600 meters in height are categorized as "supertall buildings" or "skyscrapers" and "megatall buildings", respectively.

The subsequent sections were structured as follows: Initially, an extensive review of the literature was performed. Subsequently, the research method was outlined, and the obtained results were presented. Following that, a discussion section was provided, which delved into the analysis and interpretation of the findings. Finally, a conclusion was drawn, including the practical implications, recommendations and limitations of the research.

2. Literature survey

Limited research exists in the literature that explores the concept of space efficiency in tall and supertall buildings. Previous studies have predominantly focused on analyzing a small number of tall buildings, with the exception of Ilgın's studies (2021a, b, 2023a).

Kim and Elnimeiri (2004) examined space efficiency in 10 mixed-use tall towers, emphasizing its significance in conjunction with structural and energy efficiency. They highlighted the role of elevator optimization and functional distribution strategy in increasing space efficiency and emphasized the importance of building form and load-bearing systems to enhance space efficiency.

Saari *et al.* (2006) analyzed the interrelationship between space efficiency and total building cost in tall office buildings and found that increased space efficiency significantly influenced achieving desired indoor climate comfort.

Sev and Özgen (2009) investigated spatial efficiency in ten tall office towers, considering factors such as structural material, load-bearing system, and lease span. The results highlighted the importance of core arrangement and load-bearing systems in space efficiency. Core planning varied significantly based on occupant needs, and the central core typology was the most favored.

Nam (2016) examined high-rise corner forms and lease spans in terms of space efficiency. They found that square-cut corner forms had the most negative impact on space efficiency, while lease span had a significant effect on space efficiency.

Arslan Kılınç (2019) utilized regression analysis to analyze factors influencing service core and load-bearing systems in prismatic tall buildings. The study revealed that taller office towers allocated larger areas to the structural system and service core. However, no significant scientific relationship was found between space efficiency and construction material.

Suga (2021) focused specifically on space efficiency in hotel buildings. It was found that designs prioritizing space efficiency positively impacted hotel projects, with particular importance placed on the effective arrangement of common areas in relation to guest room size.

Hamid *et al.* (2022) conducted interviews with architectural companies to investigate space efficiency in 60 single-family dwellings in Sudan. Factors such as courtyard and plot positioning, as well as vertical circulation components, were taken into account. The findings revealed that corner positioning of the buildings provided the most effective land utilization, while the optimum placement for vertical circulation elements was in the middle of building edges. It was also observed that the highest space efficiency ratio was achieved when the plot dimensions had a longer width than depth.

Okbaz and Sev (2023) developed a model to understand space efficiency in 11 freeform office towers. Their analysis considered planning considerations such as the service core and load-bearing elements. The results indicated that freeform designs exhibited lower space efficiency compared to conical forms, while the floor–floor height had a negligible effect.

Tuure and Ilgın (2023) investigated the space efficiency of 55 mid-rise wooden apartments in Finland. Their findings revealed that (a) space efficiency ranged between 78% and 88% on average, with a mean of 83%, and (b) no discernible scientific correlation was identified between the number of stories and space efficiency.

Ilgın (2021a) investigated space efficiency in 44 office skyscrapers, considering major architectural and structural planning issues, while Ilgın (2021b) examined space efficiency in 27 residential skyscrapers, considering similar design parameters. Additionally, Ilgın (2023b) explored space efficiency in 64 towers with mixed-use functions. The collective findings from Ilgın's studies indicated that a central core typology was the most favored, outriggered frame systems were commonly employed as load-bearing systems, and there was an inversely proportional relationship between space efficiency and building height.

As indicated by the literature review outlined above, there is a scarcity of research examining the space efficiency in tall and supertall buildings. Existing studies primarily focus on functional aspects [e.g. Ilgın (2021a, 2023a)] and/or architectural design [e.g. Okbaz and Sev (2023)] of these towers. There is a noticeable gap in the literature when it comes to comprehensive research on space efficiency in skyscrapers located in Asia, which is home to the largest number and tallest towers in the world. The objective of this research initiative is to fill this substantial gap within the current academic literature.

3. Research method

The methodology employed in this study involved a case study approach to gather data on Asian supertall towers in order to examine space efficiency. This method is widely used in the assessment of built-environment projects, providing a means to collect both quantitative and qualitative data (Tulonen *et al.*, 2021; Saarinen *et al.*, 2022; Rinne *et al.*, 2022; Ilgın and Karjalainen, 2023). A total of 75 supertall cases from Asia were included in the analysis. Detailed information on each case was provided in Appendix. The majority of these buildings, approximately 90%, have been completed within the last two decades and include notable skyscrapers such as the Shanghai Tower and Ping An Finance Center. Supertall towers lacking sufficient and accessible information on space efficiency or floor plans were excluded from the case study samples.

The author demonstrated meticulous effort in examining the floor plans of supertall towers in Asia, including typical, low-rise or ground floors. This thorough approach enabled the collection of reliable data for evaluating space efficiency in 75 supertall towers. Furthermore, in consideration of the existing literature (e.g. Ilgın, 2006; Gunel and Ilgın, 2007; Taranath, 2016; Ali and Moon, 2018; Ali and Al-Kodmany 2022), the author utilized Ilgın's (2023b) comprehensive categories for key architectural and structural planning considerations. This decision was made based on the categories' comprehensive nature, as depicted in Figure 1.

Space efficiency refers to the ratio of the net floor area (NFA) to gross floor area (GFA). This aspect is particularly crucial for investors as it involves maximizing the useable space within floor plans to achieve the highest possible returns. The level of space efficiency is primarily influenced by factors such as the load-bearing system, the form of the building, as well as the configuration of the floor slabs (Ilgın, 2023a). Additionally, the concept of space efficiency is significant in determining the lease span, which represents the distance between fixed internal elements like service core walls and the building envelope like windows (Ilgın *et al.*, 2023).

4. Findings

4.1 Main architectural design considerations: function, core typology and building form

In terms of building function, the case study sample exhibited a predominant presence of mixed-use developments, accounting for over 55% of the sample. Office use followed with a percentage of 38%, as illustrated in Figure 2. The high proportion of mixed-use towers can be attributed to the vertical communities approach, which offers solutions to accommodate population growth and mitigate urban sprawl. The preference for mixed-use function has further increased, particularly during market fluctuations, as it allows for higher rental profits and diversification of the customer base (Ilgın, 2023a). Conversely, the demand for

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

Source(s): Figure by author

Figure 1.
Core, structural system and material classifications

office towers may be attributed to the tendency for commercial activity areas to be clustered closely together, driven by the process of urbanization in Asia (Gunel and Ilgın, 2014a).

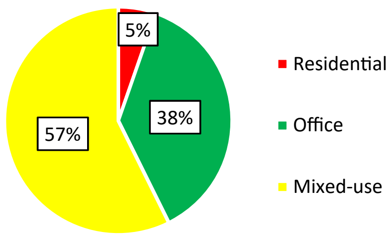
With the exception of Hanking Center Tower, which features an external core, the majority of supertall towers in Asia follow a consistent central core strategy. The preference for a central core can be attributed to several factors, including its compact structure, substantial contribution to the overall structural system and its ability to facilitate efficient fire escape scenarios (Ilgın *et al.*, 2021). The limited popularity of the external core type may be due to the extension of circulation distances and the resulting longer fire escape routes (Ilgın, 2018).

According to Figure 3, tapered forms were the most commonly used design approach in the 27 analyzed skyscrapers, accounting for 36% of the cases. This was followed by free forms, which represented 27% of the sample. The preference for tapered forms in Asian skyscraper projects, as seen in Suzhou Zhongnan Center, could be attributed to their favorable aerodynamic properties, considering the significance of wind-induced lateral loads as a critical factor in the structural design of skyscrapers (Gunel and Ilgın, 2014b). Similarly, the utilization of free forms may have gained popularity due to their aerodynamic superiority and the tendency of skyscraper architects to create iconic structures.

4.2 Main structural design considerations: structural system and structural material

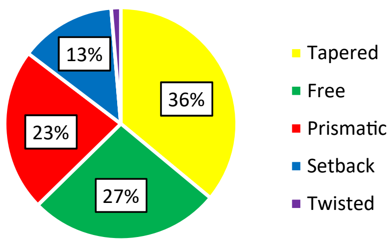
Figure 4 illustrates that outriggered frame systems were the most frequently utilized structural system in Asian skyscrapers, accounting for over 75% of the cases. Tube systems were the second most prevalent, representing 17% of the sample. The outriggered frame system is favored due to its ability to offer relative flexibility in the placement of outer columns, thereby providing architects with more design freedom for the building envelope. Additionally, its suitability for achieving great heights in skyscraper construction contributes to its popularity (Ilgın, 2023c, 2023d).

Figure 5 demonstrates that composite construction was the dominant choice in the case studies, accounting for 79% of the sample. Reinforced concrete was the second most



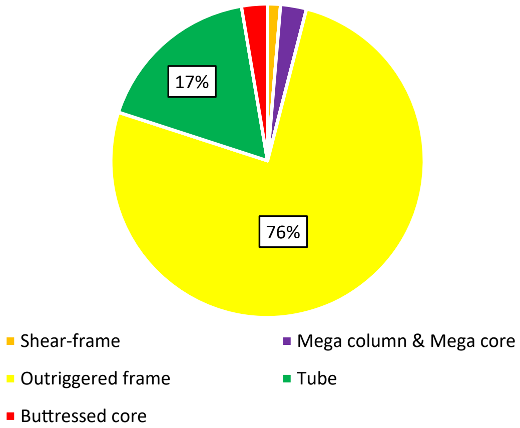
Source(s): Figure by author

Figure 2. Asian supertall towers by function



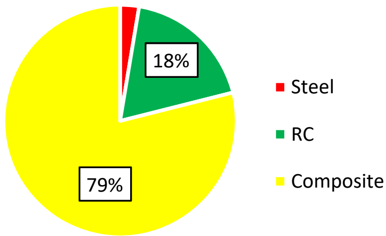
Source(s): Figure by author

Figure 3. Asian supertall towers by form



Source(s): Figure by author

Figure 4.
Asian supertall towers by structural system



Source(s): Figure by author

Figure 5.
Asian supertall towers by structural material

prevalent, comprising 18% of the cases. The prevalent use of composite construction in Asian supertall towers can be attributed to the advantageous combination of steel's tensile strength and concrete's compressive strength, as well as the fire resistance properties of concrete.

4.3 Space efficiency and interrelations with main design criteria

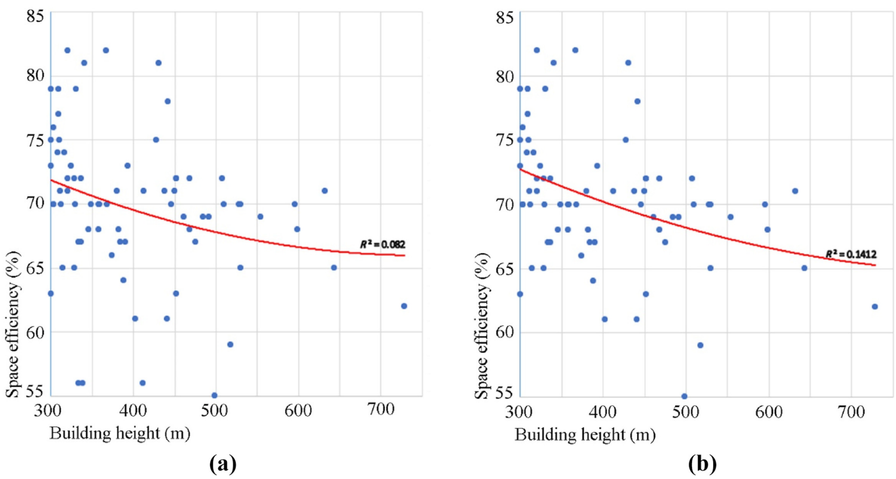
The threshold ratio for space efficiency in tall towers can be considered as 75% (Yeang, 2000). In Ilgın's (2021a) study on tall office towers, the average space efficiency and core over GFA ratio were found to be 71% and 26%, respectively. The lowest recorded values were 63% for space efficiency and 15% for core over GFA, while the highest values were 82% and 36%, respectively. In the research conducted by Ilgın (2021b) on residential towers, the average space efficiency and core over GFA ratio were 76% and 19%, respectively. The lowest recorded values were 56% for space efficiency and 11% for core over GFA, while the highest values were 84% and 36%, respectively. In Ilgın's (2023b) article focusing on contemporary mixed-use supertall buildings, the average space efficiency and core over GFA ratio were 71% and 26%, respectively. The lowest recorded values were 55% for space efficiency and 16% for core over GFA, while the highest values were 84% and 38%, respectively. In this article, based on the analysis of 75 supertall towers in Asia, the average space efficiency and core over GFA ratio were determined as 67.5% and 29.5%, respectively. The lowest recorded values were 55% for space efficiency and 14% for core over GFA, while the highest values were 82% and 38%, respectively (refer to Appendix for more details).

4.3.1 Interrelation of space efficiency and the height of the building. Figures 6a and b illustrate the relationship between space efficiency and the height of Asian skyscrapers. In these figures, the dots represent the Asian skyscrapers included in the case study. To account for correlations, a polynomial regression approach was employed, as it provides a more accurate *R*-square correlation coefficient compared to linear or exponential approaches. It is worth noting that LCT The Sharp Landmark Tower, LCT The Sharp Residential Tower A, and Tower B, which exhibit 56% space efficiency and 36% core to GFA ratios, were identified as outliers. Figure 6b demonstrates how the presence of outliers affects the regression line. As depicted by the trendline in Figure 6a, there is a tendency for space efficiency to decrease with increasing height. Furthermore, when the outliers are removed, the declining trend becomes more pronounced, as depicted in Figure 6b. This decreasing trend can be attributed to the fact that as skyscrapers rise in height, the size of the core and load-bearing elements increases, making it challenging to achieve high space efficiency ratios, as highlighted by Ilgın (2021a, 2023b).

Figures 7a and b provide further insight into the ratio of core to GFA in relation to the height of the tower, complementing the previous statement regarding the increasing requirement for larger service cores as the tower height increases, as reported by Ilgın (2021b). Similar to Figure 6b, the removal of outliers results in a more pronounced upward trend, as depicted in Figure 7b.

4.3.2 Interrelation of space efficiency and building form. Figure 8 illustrates the distribution of Asian supertall buildings by form, represented by the total number of buildings shown as bars on the right axis. The space efficiency of these buildings for each respective building form is depicted by blue dots, while the red dots on the graph indicate the tallest Asian skyscraper having the respective building form. The black bar illustrates the number of supertall buildings within the sample group employing the respective building form.

On average, prismatic and setback forms exhibited a space efficiency of 70%. Tapered forms, which were the most preferred, had space efficiency ranging from 55% to 81% with an average of 70% across 27 towers. A single tower with a twisted form achieved a space efficiency of over 70%. Freeformed Asian towers had space efficiency ranging from 61% to 79% with an average of 69%. Therefore, considering above-average values, there was no significant difference in the impact of various forms on space efficiency in Asian skyscrapers.



Source(s): Figure by author

Figure 6. The interrelationship between space efficiency and height: (a) including outliers, (b) excluding outliers

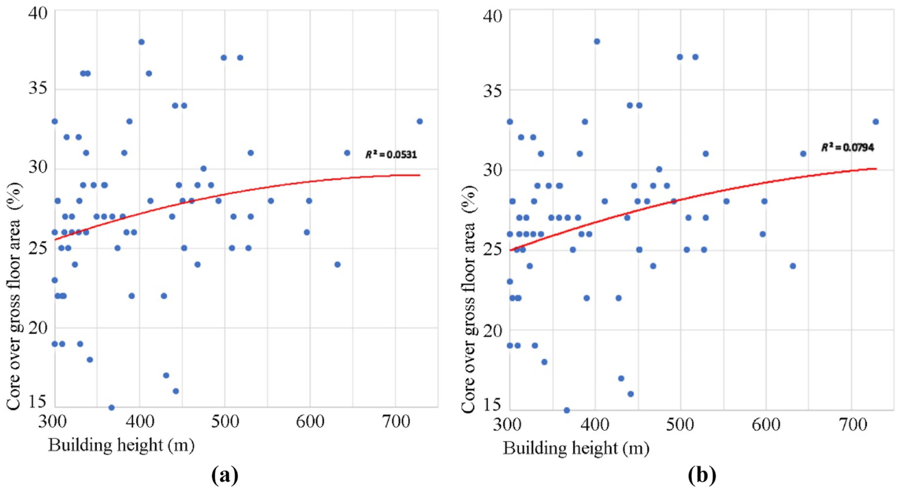


Figure 7. The interrelationship between core over GFA and height: (a) including outliers, (b) excluding outliers

Source(s): Figure by author

4.3.3 Interrelation of space efficiency and structural system. Figure 9 displays the total number of Asian skyscrapers, represented by bars on the right axis, categorized by their load-bearing system. The space efficiency of these structures for each specific load-bearing system is depicted by blue dots, while the red dots on the graph indicate the tallest Asian skyscraper using the respective structural system. The black bar illustrates the number of supertall buildings within the sample group employing the respective structural system.

Among the various load-bearing systems used in Asian skyscrapers, outriggered frame systems were the most common, with 57 towers utilizing this system. These towers exhibited a space efficiency ranging from 55% to 82%, with an average of 70%. On the other hand, the shear-frame system, which was the least preferred load-bearing system and employed in only one tower, achieved a space efficiency rate of 67%. Mega column and mega core systems and buttressed core systems were also infrequently utilized, each with two towers. The space efficiency of towers constructed with tube systems, totaling 13 towers, ranged from 61% to 82% with an average of 69%. Considering the aforementioned average values, it can be concluded that the impact of different load-bearing systems on space efficiency in Asian skyscrapers does not show significant variation.

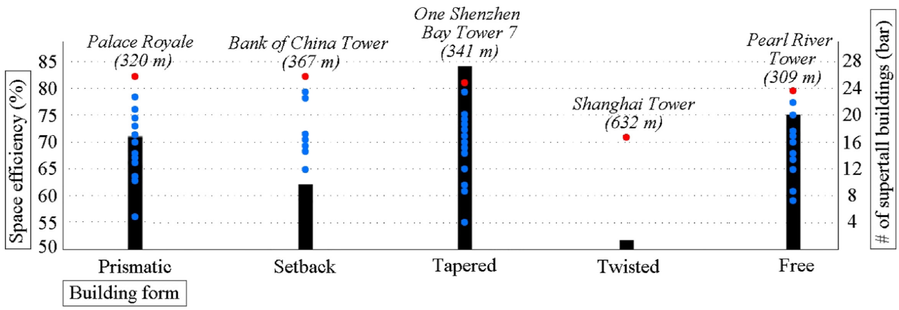
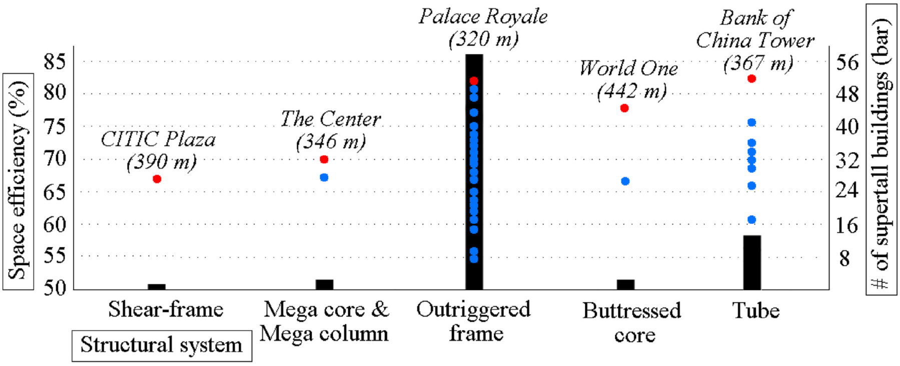


Figure 8. The interrelationship between space efficiency and building form

Source(s): Figure by author



Source(s): Figure by author

Figure 9. The interrelationship between space efficiency and structural system

5. Discussion

The findings demonstrated both similarities and differences when compared to previous studies, such as Oldfield and Doherty (2019) and Ilgın (2023b). The key findings of the research can be summarized as follows:

(1) The average space efficiency of Asian skyscrapers was 67.5%, ranging from a minimum of 55% to a maximum of 82%.

(2) The average core over GFA ratio was 29.5%, with values ranging from a minimum of 14% to a maximum of 38%.

(3) Tapered forms were the most common among Asian skyscrapers, and central core typology was predominantly used for mixed-use and office purposes.

(4) The composite construction and outriggered frame system were the most frequently employed structural systems.

(5) There was an inverse relationship observed between the height of the tower and its space efficiency.

(6) The study found no considerable difference in the impact of different load-bearing systems and building forms on space efficiency.

These findings provide valuable insights into the characteristics and trends of Asian skyscrapers, shedding light on important aspects such as space efficiency, core design, building form and structural systems.

Based on Yeang's investigation (2000), which considers the 75% space efficiency threshold for tall towers, Asian skyscrapers exhibit a deficiency in space efficiency, averaging 67.5%. Similarly, the average space efficiencies (71%) reported by studies of Ilgın (2021b, 2023b) on office and mixed-use skyscrapers were below the Yeang's threshold. These inadequacies can be largely attributed to the dimensions of service core area and structural elements. The majority of Asian supertall buildings exhibited a preference for tapered forms, which aligns with the findings of Ilgın (2023b) regarding supertall office towers. However, Ilgın's (2021b) study on supertall residential towers highlighted the popularity of prismatic forms. The central core configuration emerged as the favored choice among the sampled buildings, consistent with the findings of Oldfield and Doherty (2019) and Ilgın (2021a). These Asian skyscrapers were primarily designed for mixed-use and office purposes, which corroborates the results reported by Ilgın *et al.* (2021). Outriggered frame systems and composite materials were widely employed as load-bearing systems and structural materials, respectively, as indicated by the research conducted by Ilgın (2021a, 2023b). The papers by Sev and Özgen (2009) and Arslan Kılınç (2019) demonstrated that space efficiency tends to decrease with increasing building height due to the larger core space area and structural system elements at greater heights. The results regarding the relationships between space efficiency and structural systems, as well as space efficiency and building forms, align with the findings of Ilgın (2021b, 2023b). These studies found no significant differences in the impact of load-bearing systems on space efficiency, and similar results were obtained for forms, consistent with the findings of this study.

6. Conclusion

The research focused on examining space efficiency in Asian skyscrapers using a sample of 75 case study towers, with a particular emphasis on key design parameters related to architectural and structural considerations.

In the face of rapid urban expansion driven by economic growth, space efficiency has gained increasing importance for supertall towers, as they play a noteworthy role in improving the sustainability of Asian cities. In this sense, improving the space efficiency of Asian skyscrapers, which are observed to be below certain recommended thresholds, is crucial for ensuring the sustainability of these buildings. To achieve this goal, particular attention should be given to optimizing the dimensions of the service core and, consequently, circulation elements and structural systems/components. In this regard, structural designers and service core planners, with the architectural designer taking on a coordinating and leading role, play essential roles in the process. Their efforts are instrumental in enhancing the overall space efficiency and sustainability of these skyscrapers. Maintaining a seamless flow of information for every detail is imperative in this endeavor.

Despite being a demanding form for engineers in Asian towers, where wind loads can become dominant in their structural design, tapered form is expected to remain extensively utilized, primarily due to its aerodynamic benefits and adaptability for mixed-use purposes. The combination of this form with the composite outrigger structural system and central core, which offers numerous technical advantages, is projected to be a significant trend in skyscraper construction in Asia.

The tall building history in Asia is relatively brief, but certain cities, such as Shanghai in China, stand out as focal points for tall building development, drawing significant attention. Successful tall buildings frequently result from international design collaborations that incorporate the finest design practices from reputable tall building design firms. The prevailing spirit of the times embraces tall buildings as the essential building type of the present and future, leading to the creation of a superior environment for supertall structures through meticulous and thoughtful design.

Future studies on space efficiency could be conducted in other regions, particularly the Middle East, which serves as a hub for skyscrapers. The findings from such studies could be compared to those from Asian skyscrapers, offering valuable insights to enhance space efficiency and draw new lessons for improvement.

This paper is subject to certain limitations. The dataset analyzed in this study was confined to 75 supertall towers in Asia, which may restrict the generalizability of the findings. To enhance the robustness and encourage broader conclusions, future research could consider expanding the sample size by including larger case study buildings. Additionally, it is suggested that future studies encompass skyscrapers with heights below 300 meters and generate an ample number of subgroups to provide a more comprehensive analysis.

References

Al-Kodmany, K. and Ali, M.M. (2012), "Skyscrapers and placemaking: supporting local culture and identity", *ArchNet-IJAR*, Vol. 6 No. 2, p. 43.

Ali, M.M. and Al-Kodmany, K. (2022), "Structural systems for tall buildings", *Encyclopedia*, Vol. 2 No. 3, pp. 1260-1286.

Ali, M.M. and Moon, K.S. (2018), "Advances in structural systems for tall buildings: emerging developments for contemporary urban giants", *Buildings*, Vol. 8, p. 104.

Arslan Kılınç, G. (2019), *Improving a Model for Determining Space Efficiency of Tall Office Buildings*, Ph.D. dissertation, Mimar Sinan Fine Art University, Department of Architecture, Istanbul, (in Turkish).

Binder, G. (2001), *Tall Buildings of Asia and Australia*, The Images Publishing Group, Mulgrave.

CTBUH (2023), *Council on Tall Buildings and Urban Habitat*, Illinois Institute of Technology, S.R. Crown Hall, Chicago, IL, available at: https://www.ctbuh.org (accessed 1 August 2023).

Gunel, M.H. and Ilgın, H.E. (2007), "A proposal for the classification of structural systems of tall buildings", *Building and Environment*, Vol. 42 No. 7, pp. 2667-2675, doi: 10.1016/j.buildenv.2006.07.007.

Gunel, M.H. and Ilgın, H.E. (2014a), *Tall Buildings: Structural Systems and Aerodynamic Form*, Routledge, London.

Gunel, M.H. and Ilgın, H.E. (2014b), *Yüksek Bina: Taşıyıcı Sistem Ve Aerodinamik Form*, METU Faculty of Architecture Press, Ankara, ISBN: 978-975-429-278-7 (in Turkish).

Hamid, G.M., Elsawi, M. and Yusra, O. (2022), "The impacts of spatial parameters on space efficiency in hybrid villa-apartments in greater khartoum, Sudan", *Journal Architecture and Planning*, Vol. 34 No. 4, pp. 425-440.

Ilgın, H.E. (2006), "A study on tall buildings and aerodynamic modifications against wind excitation", MSc Thesis, Department of Architecture, Middle East Technical University, Ankara.

Ilgın, H.E. (2018), *Potentials and Limitations of Supertall Building Structural Systems: Guiding for Architects*, Ph.D. Dissertation, Department of Architecture, Middle East Technical University, Ankara.

Ilgın, H.E. (2021a), "Space efficiency in contemporary supertall office buildings", *Journal of Architectural Engineering*, Vol. 27 No. 3, 4021024.

Ilgın, H.E. (2021b), "Space efficiency in contemporary supertall residential buildings", *Architecture*, Vol. 1 No. 1, pp. 25-37.

Ilgın, H.E. (2022), "Use of aerodynamically favorable tapered form in contemporary supertall buildings", *Journal of Design for Resilience in Architecture and Planning*, Vol. 3 No. 2, pp. 183-196.

Ilgın, H.E. (2023a), "Interrelations of slenderness ratio and main design criteria in supertall buildings", *International Journal of Building Pathology and Adaptation*, Vol. 41 No. 6, pp. 139-161.

Ilgın, H.E. (2023b), "A study on space efficiency in contemporary supertall mixed-use buildings", *Journal of Building Engineering*, Vol. 69, 106223.

Ilgın, H.E. (2023c), "Review on supertall building forms", *Civil Engineering and Architecture*, Vol. 11 No. 3, pp. 1606-1615.

Ilgın, H.E. (2023d), "A study on interrelations of structural systems and main planning considerations in contemporary supertall buildings", *International Journal of Building Pathology and Adaptation*, Vol. 41 No. 6, pp. 1-25.

Ilgın, H.E. and Karjalainen, M. (2023), "Freeform supertall buildings, civil engineering and architecture", Vol. 11 No. 2, pp. 999-1009.

Ilgın, H.E., Ay, B.Ö. and Gunel, M.H. (2021), "A study on main architectural and structural design considerations of contemporary supertall buildings", *Architectural Science Review*, Vol. 64 No. 3, pp. 212-224.

Ilgın, H.E., Karjalainen, M. and Pelsmakers, S. (2023), "Contemporary tall residential timber buildings: what are the main architectural and structural design considerations?", *International Journal of Building Pathology and Adaptation*, Vol. 41 No. 6, pp. 26-46.

Kim, H.I. and Elnimeiri, M. (2004), "Space efficiency in multi-use tall building", *Tall Buildings in Historical Cities-Culture and Technology for Sustainable Cities*, pp. 10-13, https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Space+ef%EF%AC%81ciency+in+multi-use+tall+building&btnG=.

Moon, K.S. (2015), "Supertall Asia/Middle East: technological responses and contextual impacts", *Buildings*, Vol. 5 No. 3, pp. 814-833.

Nam, H.J. and Shim, J.H. (2016), "An analysis of the change in space efficiency based on various tall building corner shapes and lease spans", *Journal of the Architectural Institute of Korea Planning and Design*, Vol. 32 No. 8, pp. 13-20.

Okbaz, F.T. and Sev, A. (2023), "A model for determining the space efficiency in non-orthogonal high rise office buildings", *Journal of the Faculty of Engineering and Architecture of Gazi University*, Vol. 38 No. 1, pp. 113-125.

Oldfield, P. and Doherty, B. (2019), "Offset cores: trends, drivers and frequency in tall buildings", *CTBUH Journal*, No. 2, pp. 40-45.

Rinne, R., Ilgın, H.E. and Karjalainen, M. (2022), "Comparative study on life-cycle assessment and carbon footprint of hybrid, concrete and timber apartment buildings in Finland", *International Journal of Environmental Research and Public Health*, Vol. 19, p. 774.

Saari, A., Tissari, T., Valkama, E. and Seppänen, O. (2006), "The effect of a redesigned floor plan, occupant density and the quality of indoor climate on the cost of space, productivity and sick leave in an office building–A case study", *Building and Environment*, Vol. 41 No. 12, pp. 1961-1972.

Saarinen, S., Ilgın, H.E., Karjalainen, M. and Hirvilammi, T. (2022), "Individually designed House in Finland: perspectives of architectural experts and a design case study", *Buildings*, Vol. 12, p. 2246.

Sev, A. and Özgen, A. (2009), "Space efficiency in high-rise office buildings", *METU Journal of the Faculty of Architecture*, Vol. 26 No. 2, pp. 69-89.

Suga, R. (2021), "Business administration with a specialization in real estate management and development", Space Efficiency in Hotel Development, MSc Thesis, MODUL University Vienna, Vienna.

Taranath, B.S. (2016), *Structural Analysis and Design of Tall Buildings: Steel and Composite Construction*, CRC Press, Taylor and Francis Group, Boca Raton, Florida.

Tulonen, L., Karjalainen, M. and Ilgın, H.E. (2021), *Tall Wooden Residential Buildings in Finland: what Are the Key Factors for Design and Implementation?*, IntechOpen, London.

Tuure, A. and Ilgın, H.E. (2023), "Space efficiency in Finnish mid-rise timber apartment buildings", *Buildings*, Vol. 13 No. 8, p. 2094.

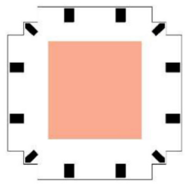
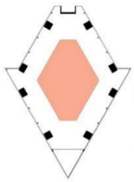
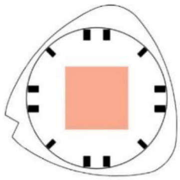
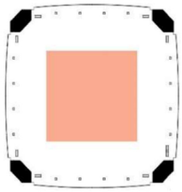
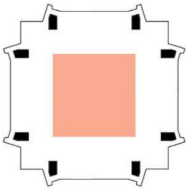
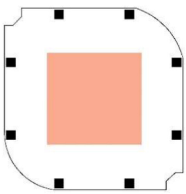
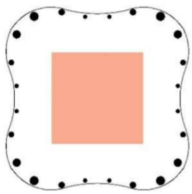
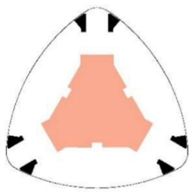
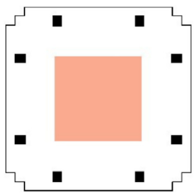
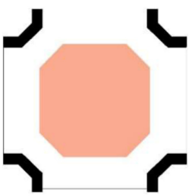
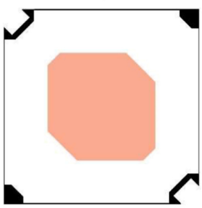
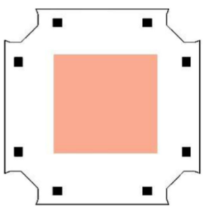
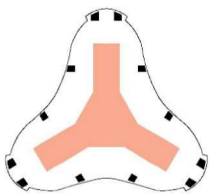
Wang, X., Shi, R. and Zhou, Y. (2020), "Dynamics of urban sprawl and sustainable development in China", *Socio-Economic Planning Sciences*, Vol. 70, 100736.

Yeang, K. (2000), *Service Cores: Detail in Building*, Wiley-Academy, London.

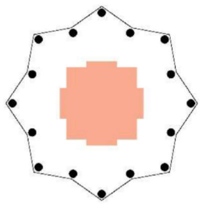
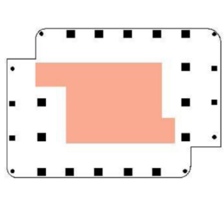
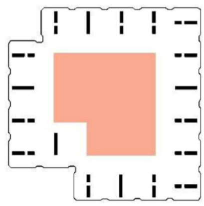
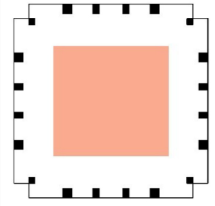
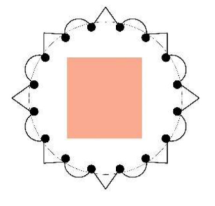
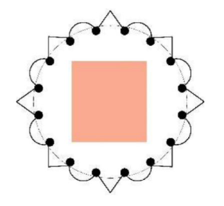
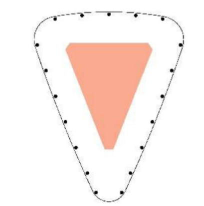
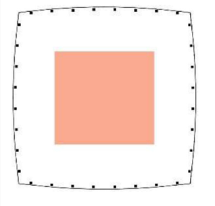
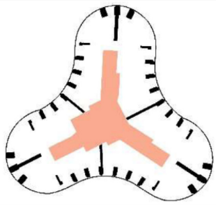
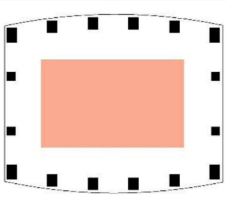
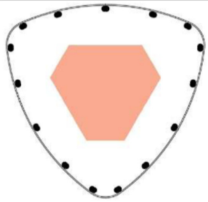
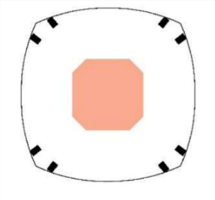
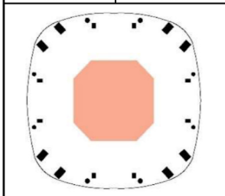
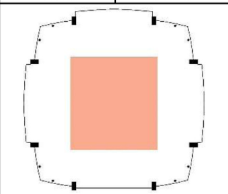
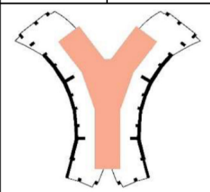
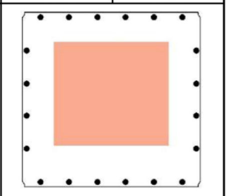
Further reading

Ilgın, H.E. (2023d), "A study on interrelations of structural systems and main planning considerations in contemporary supertall buildings", *International Journal of Building Pathology and Adaptation*, Vol. 41 No. 6, pp. 1-25.

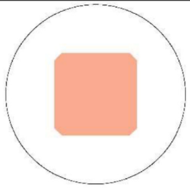
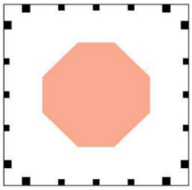
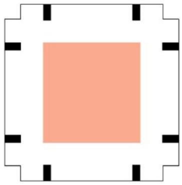
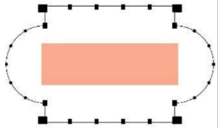
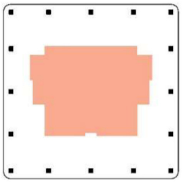
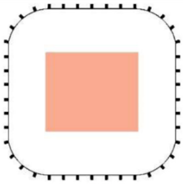
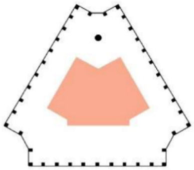
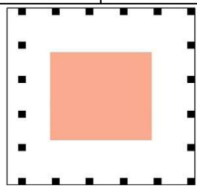
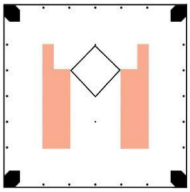
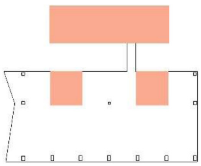
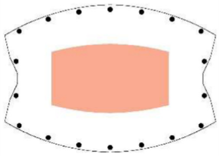
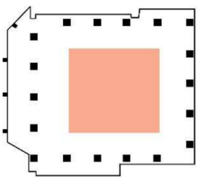
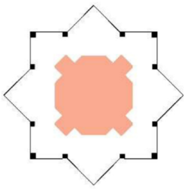
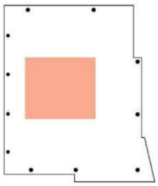
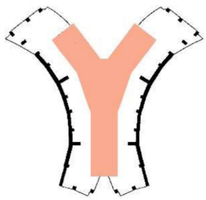
Appendix
Asian supertall buildings' floor plan, space efficiency and core/GFA ratio

Building name							
Space efficiency*				Core/GFA ratio**			
Suzhou Zhongnan Center		**Merdeka PNB118**		**Shanghai Tower**		**Goldin Finance 117**	
62%	33%	65%	31%	71%	24%	68%	28%
							
Low-rise floor		Low-rise floor		Low-rise floor		Ground floor	
Ping An Finance Center		**Lotte World Tower**		**Guangzhou CTF Finance Centre**		**Tianjin CTF Finance Centre**	
70%	26%	69%	28%	65%	31%	70%	27%
							
Low-rise floor		Low-rise floor		Low-rise floor		Low-rise floor	
CITIC Tower		**Evergrande Hefei Center 1**		**Busan Lotte Town Tower**		**TAIPEI 101**	
70%	25%	59%	37%	70%	27%	72%	25%
							
Ground floor		Typical floor		Low-rise floor		Typical floor	
Greenland Jinmao IFC		**Shanghai World Financial Center**		**International Commerce Centre**		**Wuhan Greenland Center**	
55%	37%	69%	28%	69%	29%	67%	30%
							
Ground floor		Low-rise floor		Low-rise floor		Low-rise floor	

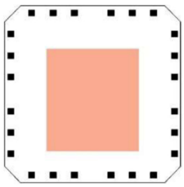
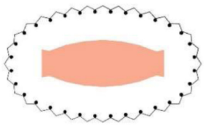
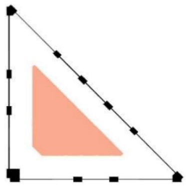
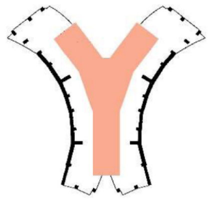
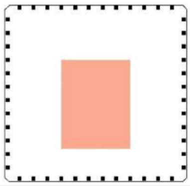
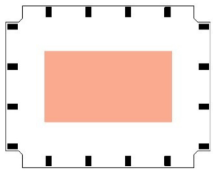
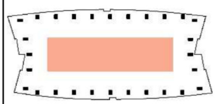
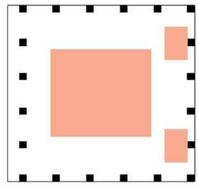
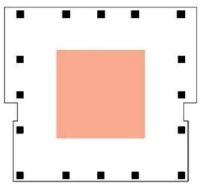
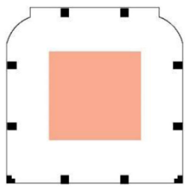
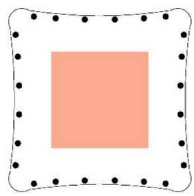
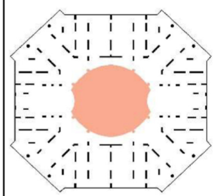
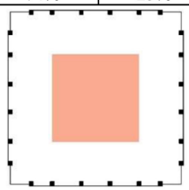
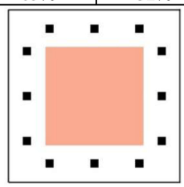
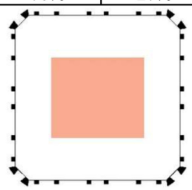
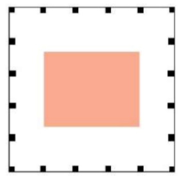
(*continued*)

Building name							
Space efficiency				Core/GFA ratio			
Chengdu Greenland Tower		R&F Guangdong Building		Vincom Landmark 81		Changsha IFS Tower T1	
72%	24%	68%	29%	69%	28%	63%	34%
							
Ground floor		Low-rise floor		Low-rise floor		Low-rise floor	
Petronas Twin Tower 1		Petronas Twin Tower 2		Zifeng Tower		The Exchange 106	
72%	25%	72%	25%	71%	28%	70%	29%
							
Typical floor		Typical floor		Ground floor		Typical floor	
World One		KK 100		Guangzhou International Finance Center		Chongqing Tall Tower	
78%	16%	61%	34%	71%	27%	81%	17%
							
Typical floor		Low-rise floor		Typical floor		Low-rise floor	
Haikou Tower 1		Two International Finance Center		LCT The Sharp Landmark Tower		Guangxi China Resources Tower	
75%	22%	71%	28%	56%	36%	61%	38%
							
Low-rise floor		Typical floor		Typical floor		Low-rise floor	

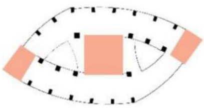
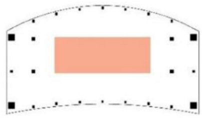
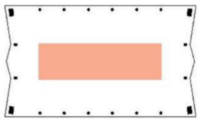
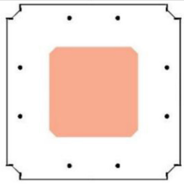
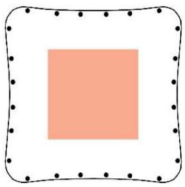
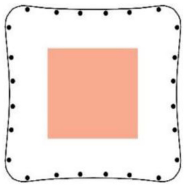
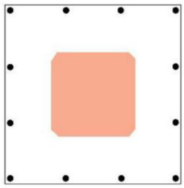
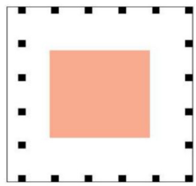
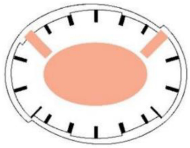
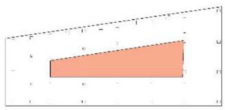
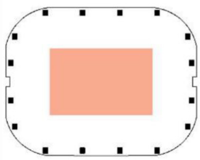
(*continued*)

Building name							
Space efficiency				Core/GFA ratio			
China Resources Tower		**CITIC Plaza**		**Shum Yip Upperhills Tower 1**		**Shun Hing Square**	
73%	26%	67%	22%	64%	33%	67%	26%
							
Typical floor		Typical floor		Typical floor		Typical floor	
Autograph Tower		**Guiyang World Trade Center Landmark Tower**		**Central Plaza**		**Golden Eagle Tiandi Tower A**	
68%	31%	71%	27%	66%	25%	70%	27%
							
Typical floor		Low-rise floor		Typical floor		Typical floor	
Bank of China Tower		**Hanking Center Tower**		**Sino Steel International Plaza T2**		**Greenland Group Suzhou Center**	
82%	15%	70%	29%	68%	27%	70%	29%
							
Low-rise floor		Typical floor		Typical floor		Low-rise floor	
Spring City 66		**The Center**		**One Shenzhen Bay Tower 7**		**LCT The Sharp Residential Tower A**	
70%	27%	68%	29%	81%	18%	56%	16%
							
Low-rise floor		Typical floor		Low-rise floor		Typical floor	

(continued)

Building name							
Space efficiency				Core/GFA ratio			
Hengqin International Finance Center		**Tianjin World Financial Center**		**Shimao International Plaza**		**LCT The Sharp Residential Tower B**	
67%	31%	72%	26%	67%	29%	56%	16%
							
Ground floor		Typical floor		Low-rise floor		Typical floor	
China World Tower		**Hon Kwok City Center**		**Keangnam Hanoi Landmark Tower**		**Golden Eagle Tiandi Tower B**	
79%	19%	70%	28%	72%	26%	65%	32%
							
Low-rise floor		Typical floor		Low-rise floor		Typical floor	
Deji Plaza		**Nina Tower**		**Sinar Mas Center 1**		**Palace Royale**	
73%	24%	71%	27%	72%	26%	82%	14%
							
Typical floor		Typical floor		Low-rise floor		Typical floor	
Chongqing IFS T1		**MahaNakhon**		**CITIC Financial Center Tower 1**		**Shenzhen Bay Innovation and Technology Centre Tower 1**	
74%	25%	65%	32%	70%	27%	71%	26%
							
Typical floor		Low-rise floor		Typical floor		Typical floor	

(*continued*)

Building name							
Space efficiency				Core/GFA ratio			
Menara TM		**Pearl River Tower**		**Fortune Center**		**Guangfa Securities Headquarters**	
75%	22%	79%	19%	77%	22%	74%	25%
							
Ground floor		Typical floor		Typical floor		Low-rise floor	
Jiangxi Nanchang Greenland Central Plaza, Parcel A		**Jiangxi Nanchang Greenland Central Plaza, Parcel B**		**Leatop Plaza**		**Golden Eagle Tiandi Tower C**	
70%	28%	70%	28%	76%	22%	75%	23%
							
Ground floor		Ground floor		Typical floor		Typical floor	
Supernova Spira		**Abeno Harukas**		**Shimao Riverside Block D2b**			
63%	33%	79%	19%	73%	26%		
							
Low-rise floor		Low-rise floor		Low-rise floor			

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

Source(s): Figure by author

Corresponding author
Hüseyin Emre Ilgın can be contacted at: emre.ilgin@tuni.fi

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: **permissions@emeraldinsight.com**