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A Comprehensive Study of Space Efficiency in Tall Buildings: the Australian Perspective

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A Comprehensive Study of Space Efficiency in Tall Buildings: the Australian Perspective

Hüseyin Emre Ilgın*

School of Architecture, Faculty of Built Environment, Tampere University, Tampere, Finland

Özlem Nur Aslantamer

Department of Interior Architecture and Environmental Design, Faculty of Art, Design and Architecture, Atılım University, Ankara, Turkey

*Corresponding author: **emre.ilgin@tuni.fi**

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Abstract

Spatial efficiency in Australian towers is shaped by a multifaceted interaction of many parameters such as architectural and structural considerations. However, there are no comprehensive studies available on space utilization in Australian high-rise towers. The article addresses this gap by investigating 32 case studies. This study aims to investigate how contemporary Australian tall buildings achieve spatial efficiency by analyzing the relationship between architectural and structural parameters and internal usable area ratios. Key findings: residential function, centrally-located core layouts, and prismatic arrangements are the most widespread trends; concrete is the favored construction material, with the shear-walled frame system being the most commonly used structural system; average space efficiency is 82%, with a core-to-GFA ratio of 16%. The paper offers valuable understandings for construction experts to inform design decisions in high-rise construction projects within the Australian context.

Keywords: tall buildings; space efficiency; architectural considerations; structural considerations; Australia.

Introduction

The increasing global interest in tall buildings is closely linked to the broader urban planning paradigm of the “Compact City.” As cities face mounting pressure from land scarcity, population growth, and infrastructure constraints, compact urban form strategies aim to reduce horizontal sprawl by promoting vertical densification and mixed-use development (Jenks et al., 1996). Within this framework, tall buildings are not merely architectural artifacts but tools for achieving sustainable urbanism. However, the Compact City model has also received critique—Neuman (2005), for instance, argues that density alone does not ensure sustainability without equal attention to accessibility, livability, and spatial quality. This study, while focusing on space efficiency in Australian tall buildings, aligns with this broader discourse by investigating how vertical development strategies contribute to efficient urban land use.

Skyscraper development in Australia reflects urban growth, innovation, and engineering advances (Dean et al., 2001). With limited land, vertical expansion met rising demand (Collins et al., 2006). Cities like Sydney and Melbourne illustrate this trend (Al-Kodmany, 2018). Early high-rises appeared by the early 20th century, with iconic buildings like Sydney’s Grace Building marking

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progress. Growth accelerated post-WWII with the economic boom (Lehmann, 2017). The construction of Sydney's 115-meter AMP Building in 1962 marked Australia's entry into the modern skyscraper era (Punter, 2005). This initiated a wave of vertical growth, with landmarks like Sydney Tower and Melbourne's Rialto Towers reshaping city skylines (Lesh, 2016). While reflecting global trends linking height to economic and technological status, these developments also addressed Australia's specific urban and economic pressures.

Tall building architecture in Australia blends global design trends with local adaptations. While early high-rises drew from Art Deco and International Style, recent designs emphasize aesthetics, space efficiency, and sustainability (Barnstone et al., 2023). Architects and engineers have consistently balanced elegance with practicality, addressing Australia's unique urban, climatic, and economic conditions (Dowling et al., 2024).

Structural engineering breakthroughs—like reinforced concrete, high-strength steel, and innovative foundations—have enabled Australia's tall buildings to withstand natural forces (Li & Hao, 2016; Gissing et al., 2022). Modern features such as smart elevators, advanced façades, and efficient HVAC systems enhance both sustainability and spatial use (Shirazi et al., 2023). Innovations in lightweight, sustainable materials and modular construction further reduce waste and optimize efficiency (Karuppasamy et al., 2023).

Economically, Australia's rising property market and limited urban land—especially in cities like Sydney and Melbourne—have made vertical development essential (Murray, 2021). Geographic and infrastructural constraints drive the need to maximize usable space, making tall buildings vital for profitability and sustainable land use through compact, multifunctional design.

Space efficiency is critical in high-density Australian cities like Sydney, Melbourne, and Brisbane. By optimizing land use, skyscrapers alleviate pressure on infrastructure and reduce urban sprawl. Efficient layouts increase developer revenue and tenant affordability, especially where land prices are high. Environmentally, space-efficient buildings lower resource use and energy demands, while supporting public transport and walkability. Studies on spatial efficiency span diverse building types. Tuure & Ilgın (2023) reported 78–88% efficiency in Finnish wooden apartments, while Ilgın (2021a, 2021b, 2023a) linked height and structural systems (e.g., outriggered frames, central cores) to efficiency in supertall towers. In office designs, Höjer et al. (2023) and Okbaz & Sev (2023) explored space-saving strategies, highlighting conical forms. Contextual factors also matter—regulations (Ibrahimy et al., 2023), emerging tech (Goessler & Kaluarachchi, 2023), and land use patterns (Hamid et al., 2022). Design choices, as seen in hotel (Suga, 2021) and structural research (Arslan Kılınç, 2019), are crucial.

Methodological shifts—stakeholder involvement (von Both, 2019), digital tools (Höjer & Mjörnell, 2018), and lease span (Nam & Shim, 2016) —have enriched the field. Earlier studies (Sev & Özgen, 2009; Saari et al., 2006; Kim & Elnimeiri, 2004) explored the role of core layouts and economic drivers. Although tall buildings have proliferated in Australian cities, there remains a notable gap in systematic studies focusing on their internal space efficiency. This research addresses that gap by investigating how key design parameters affect the spatial efficiency of 32 tall buildings across Sydney, Melbourne, Brisbane, and the Gold Coast. The aim of this study is to identify which architectural and structural parameters—such as building function, core layout, form, structural material, and system—contribute to higher internal space efficiency in contemporary tall buildings in Australia. The central research question guiding this study is: *"Which architectural and structural strategies contribute to higher internal space efficiency in contemporary Australian high-rises?"* This framing links directly to our empirical analysis and supports more informed design decisions in dense urban contexts.

This study focuses solely on spatial efficiency, excluding sustainability factors like energy use and resilience due to inconsistent data across cases (Ilgın, 2023a; Ilgın, 2023b; Okbaz & Sev, 2023). By narrowing the scope, this research ensures a more accurate analysis of spatial design, while setting the stage for future studies incorporating sustainability when reliable data becomes available.

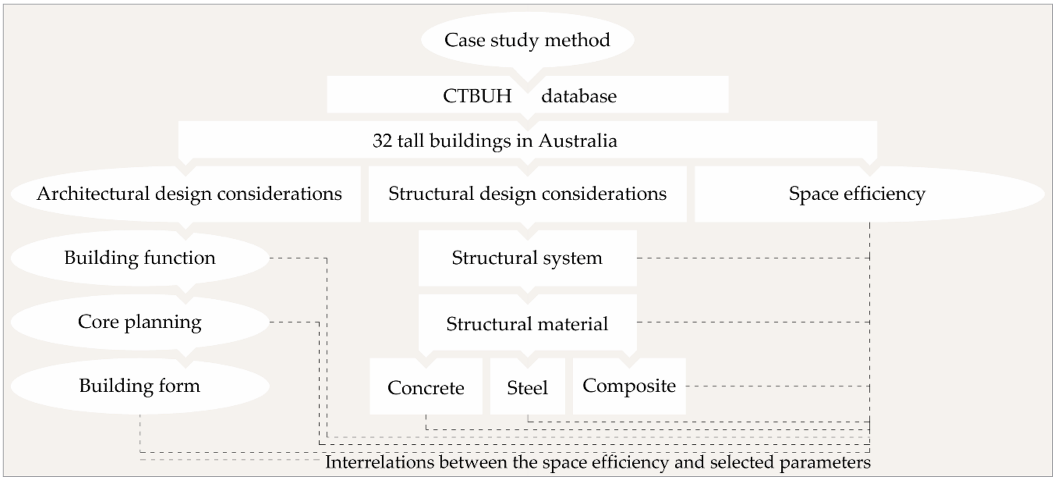
It is worth noting that this study specifically focuses on the internal space efficiency of tall buildings—measured through NFA-to-GFA and core-to-GFA ratios—and does not include a detailed analysis of the buildings' external spatial context, such as urban density, inter-building distances, or skyline composition. These aspects represent a valuable future research direction.

Methods

This study adopts a qualitative–quantitative case study approach to investigate space efficiency in Australian tall buildings. Widely used in research for its ability to integrate qualitative and quantitative data while supporting comprehensive literature reviews, this method enables a detailed examination of architectural and structural components (Pan et al., 2023). A total of 32 buildings were purposively selected from four major cities—Sydney, Melbourne, Brisbane, and the Gold Coast—based on criteria such as function, form, structural system, and data availability (Fig.1). Spatial data were collected from BIM/CAD drawings and the CTBUH database, focusing on representative typical floor plans. The analysis employed two internationally recognized metrics—Net Floor Area to Gross Floor Area (NFA/GFA) ratio and core-to-GFA ratio—to evaluate internal space efficiency. These values were then examined in relation to five key architectural and structural parameters to identify performance patterns across building types.

Fig. 1

Research methodology (by authors)



By applying this approach, researchers gain insights into the distinct design characteristics of each project, identifying patterns of consistency and variation in contemporary Australian skyscrapers. This method also facilitates an in-depth exploration of the practical applications and implications of design and structural decisions, enriching architectural and structural research. Its comprehensive nature ensures a full analysis of each case, providing critical contextual insights essential for advancing the discipline.

This study adopts the CTBUH definition of tall buildings—structures at least 14 stories or 50 meters in height, up to 300 meters—to align with global standards (CTBUH, 2025). As an authoritative body, CTBUH also sets height classifications and honors innovation through programs like "Buildings of Distinction." The selected 32 Australian towers offer a diverse and representative sample, enabling analysis of spatial trends across various heights and regions (Fig. 2), as well as years (Fig. 3).

Prior research suggests that around 30 case studies provide sufficient analytical depth and scope (Nam & Shim, 2016; Ilgın & Aslantamer, 2024). This study's 32-case sample offers a reliable basis for exploring spatial utilization in Australian high-rises, allowing detailed analysis of core design (Fig. 4a), forms (Fig. 4b), structural systems (Fig. 4c), and materials to reveal current design trends.

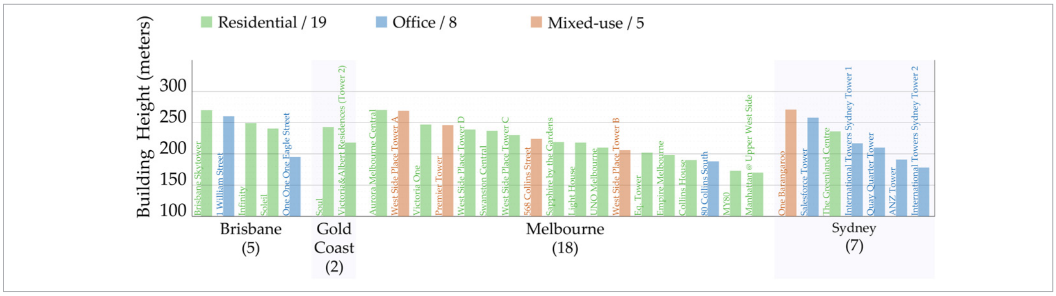


Fig. 2

Case studies by heights and regions (by authors)

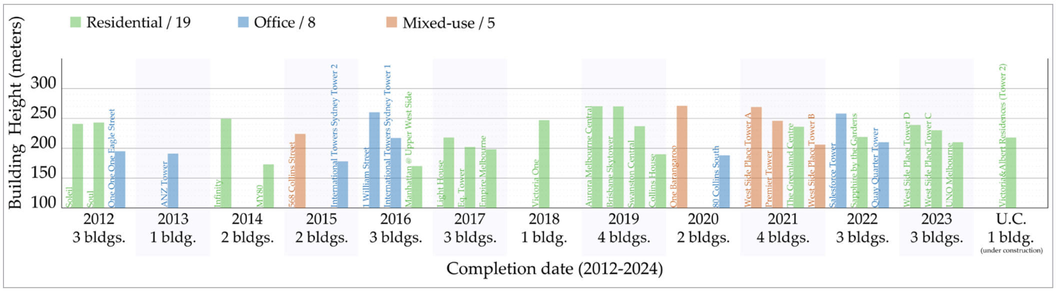


Fig. 3

Case studies by years (by authors)

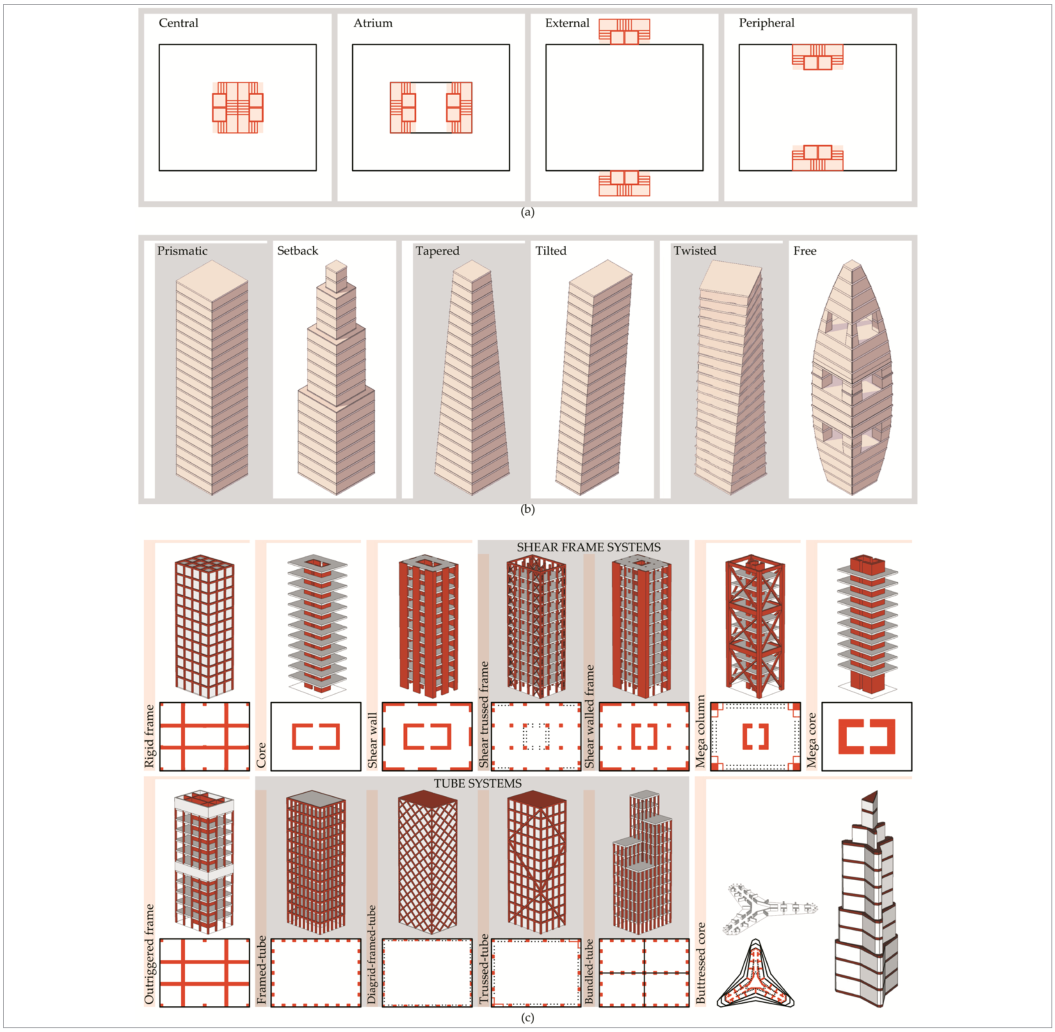


Fig. 4

Classifications by (a) core design; (b) form; and (c) structural system (by authors)

The selection of the 32 case studies followed a purposive sampling strategy designed to ensure both representativeness and data reliability. Buildings were chosen based on three key criteria: (1) geographic distribution across Australia's four main high-rise hubs (Sydney, Melbourne, Brisbane, and the Gold Coast) (Fig. 5), (2) typological diversity in function and form (residential, office, and mixed-use; prismatic and free-form), and (3) availability of accurate and consistent documentation (from BIM/CAD drawings, CTBUH database, or architectural records). The sample includes buildings completed between 2012 and 2023 and meets the CTBUH definition of tall buildings (14+ stories or >50 meters). This structured selection approach enhances the comparability and relevance of findings within the Australian high-rise context. Unlike prior studies analyzing every floor (e.g., Tuure & Ilgın, 2023; Ilgın, 2021a, 2021b, 2023a), this study examines representative typical floor plans due to limited access to full documentation. Floor plan selection was based on typological, structural, and functional criteria, focusing on standardized layouts that recur vertically rather than unique ground or top floors (Appendix A). Despite vertical variation, these plans reliably reflect overall spatial trends. By analyzing similar building types and functions, the study ensures methodological consistency and strengthens the validity of its findings.

Fig. 5

Examined towers on the Australian map (by authors)

Like high-rises in Asia, the Middle East, and North America (Ilgın, 2023b, 2024; Ilgın & Aslantamer, 2024), Australian towers are shaped by factors such as function, core layout, form, structural system, and materials. These elements impact both design and performance. Structural frameworks critically influence space utilization by shaping the layout of load-bearing elements. This study adopts Aslantamer and Ilgın's (2024) classification for tall buildings. Material selection—categorized as steel, concrete, or composite—also affects spatial efficiency, especially in vertical load-bearing components like columns. "Composite" denotes combined concrete-steel systems used for enhanced high-rise performance.

Space efficiency, defined as the ratio of NFA) to GFA, is a key indicator of optimal space use in tall buildings (Ilgın, 2022). Maximizing it enhances financial returns, with architectural and structural design playing a central role in space allocation. This study evaluates space efficiency using international standards such as BOMA, RICS, and IPMS (2024), along with recent research (Xie et al., 2022). Two key metrics are employed: the NFA-to-GFA ratio, which reflects the proportion of usable space, and the core-to-GFA ratio, which indicates the share allocated to structural and service elements. A higher NFA-to-GFA ratio signals more efficient functional space use, while a lower core-to-GFA ratio reflects better spatial optimization. Core areas include vertical circulation, MEP systems, and service zones. These ratios provide insight into how well a building balances utility, performance, and economic viability.

Applied to 32 high-rises across Australia, the analysis uses BIM/CAD data or redrawn and scaled plans to ensure precision. Representative floor plans were purposively sampled to reflect typical layouts. This hybrid methodology ensures accurate, consistent, and globally aligned assessment of spatial efficiency in tall buildings.

Results

Architectural considerations

The functional distribution in **Fig. 6** 59% residential, 25% office, and 16% mixed-use reflects strategic urban planning and socio-economic trends in Australia. The predominance of residential space responds to rising urban populations, particularly in Sydney and Melbourne, where vertical housing mitigates land scarcity and urban sprawl. High land costs further drive developers to prioritize residential density in high-rise projects.

Office space (25%) remains vital for business districts, benefiting from proximity to transport networks and corporate hubs. However, remote work trends have reduced office demand, shifting preference toward residential and mixed-use developments.

The 16% mixed-use allocation reflects a growing focus on integrated urban ecosystems, combining residential, commercial, and leisure functions. This model enhances convenience, reduces commuting, and fosters vibrant, multifunctional neighborhoods, aligning sustainable urban design principles to improve quality of life and lower carbon footprints.

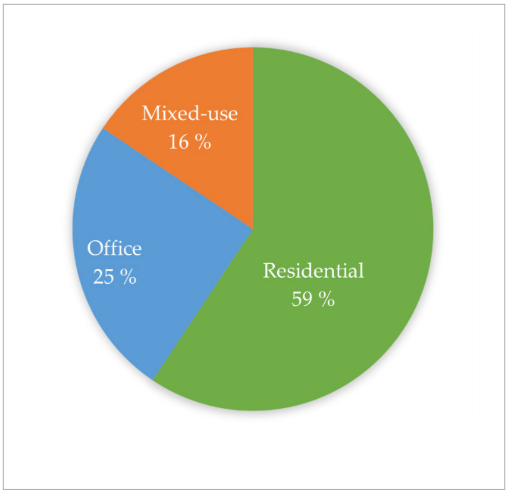


Fig. 6
Australian towers by function

The core distribution illustrated in **Fig. 7**, with over 85% of space allocated to central cores and only 13% to peripheral areas, reflects a typical design strategy in Australian high-rise buildings. Central cores, which accommodate essential vertical circulation elements such as elevators, stairwells, mechanical shafts, and service ducts, dominate the spatial layout due to their efficiency in maximizing usable floor area while maintaining structural integrity (Oldfield & Doherty, 2019). Concentrating these elements centrally optimizes structural load distribution and minimizes disruptions to open floor plans, enhancing flexibility in residential and office layouts.

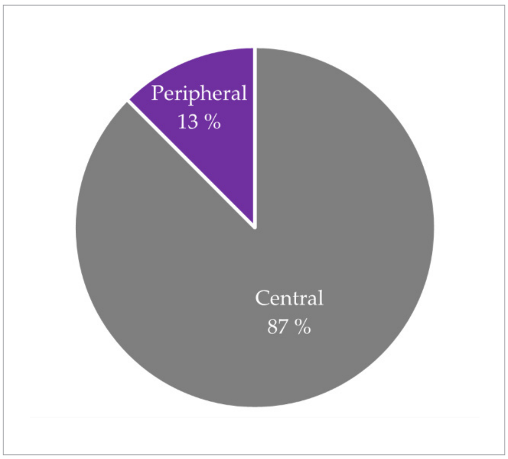
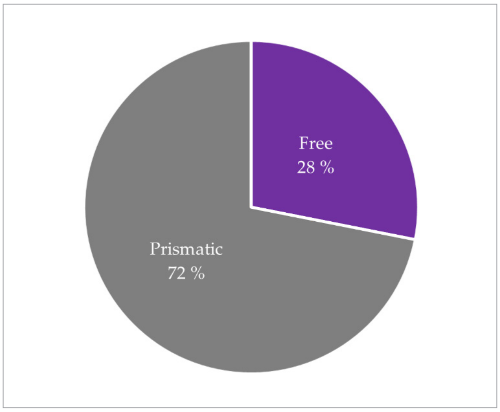


Fig. 7
Australian towers by core planning

The 13% allocation to peripheral areas is generally designated for secondary services, including emergency staircases, maintenance corridors, and peripheral circulation. These elements are strategically positioned to comply with safety regulations while being minimized to preserve the majority of space for primary uses (Barsim et al., 2020). In Australia's urban high-rises, where space efficiency is a priority, this core-centric distribution balances functionality, structural efficiency, and the maximization of rentable or habitable areas while ensuring compliance with safety and building codes.

Fig. 8
Australian towers by form



The building form distribution illustrated in **Fig. 8**, with 72% prismatic and 28% free-form structures, reflects dominant architectural trends in Australian high-rises. Prismatic forms, defined by their regular geometric shapes, prevail due to their structural efficiency, cost-effectiveness, and ease of construction (Ilgın & Karjalainen, 2022; Ilgın & Aslantamer, 2024; James, 2017). These forms facilitate modular construction techniques, enabling the repetitive use of structural and design components, which reduces material waste and accelerates construction—critical factors in large-scale urban developments. Additionally, prismatic structures optimize floor space utilization, making them particularly suitable for residential and office functions.

The 28% share of free-form designs in the sample reflects a growing focus on architectural innovation. With fluid, non-orthogonal geometries, these buildings enhance urban identity and often become landmarks. Enabled by advances in engineering and materials (Le et al., 2018), free-form structures balance creative expression with structural performance, complementing the functional efficiency of prismatic forms. **Table 1** shows findings about function, core type, and form, comparing Australian high-rise buildings with those in Asia (Ilgın, 2023b), the Middle East (Ilgın, 2024), and North America (Ilgın and Aslantamer, 2024).

Table 1
Key architectural considerations in other regions

	Australia	Asia	The Middle East	North America
Function	Mixed-use (16%) Office (25%) Residential (59%)	Mixed-use (57%) Office (38%) Residential (5%)	Mixed-use (33%) Office (22%) Residential (45%)	Mixed-use (42%) Office (32%) Residential (22%) Hotel (3%)
Core type	Central (87%) Peripheral (13%)	Central (99%) External (1%)	Central (96%) External (4%)	Central (90%) Peripheral (10%)
Form	Prismatic (72%) Free (28%)	Prismatic (23%) Setback (13%) Tapered (36%) Twisted (1%) Free (27%)	Prismatic (45%) Setback (7%) Tapered (7%) Twisted (4%) Free (37%)	Prismatic (26%) Setback (29%) Tapered (26%) Free (19%)

Structural considerations

As shown in **Fig. 9**, 75% of Australian tall buildings use reinforced concrete, 22% composite materials, and only 3% steel—highlighting local construction preferences (Le et al., 2018). Reinforced concrete is favored for its cost-effectiveness, fire resistance, thermal mass, and availability, with technological advances enabling its use in taller and more complex designs.

The 22% adoption of composite materials, typically combining concrete and steel, highlights a growing shift toward optimizing structural performance. Composite systems enhance load-bearing capacity, improve seismic resilience, and allow for greater design flexibility, making them particularly suitable for buildings in areas susceptible to dynamic forces (Don et al., 2023).

The minimal use of steel (3%) is primarily due to its higher cost and lower availability compared to concrete, as well as the economic preference for locally sourced materials. While steel frameworks enable rapid construction, they are less prevalent in Australia's high-rise sector, where reinforced concrete remains the more practical choice. This distribution reflects a strategic balance between cost efficiency, structural performance, and environmental sustainability, aligning with Australia's emphasis on durable and resource-efficient construction practices in urban development.

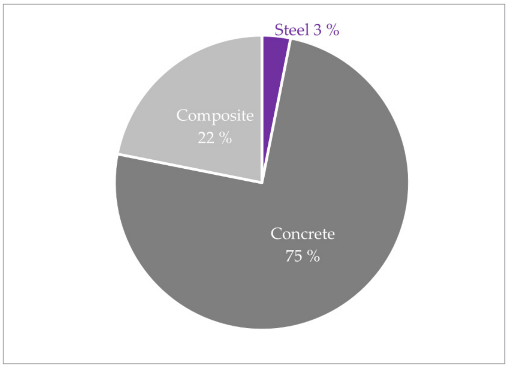


Fig. 9

Australian towers by structural material

Fig. 10 shows that 59% of Australian tall buildings use shear-walled frames, 38% employ outriggered frames, and only 3% rely solely on shear walls—highlighting structural strategies for balancing stability and design flexibility. The dominance of shear-walled frames reflects their efficiency in resisting lateral forces, especially wind, through reinforced concrete walls that offer high stiffness and stability (Bai et al., 2021).

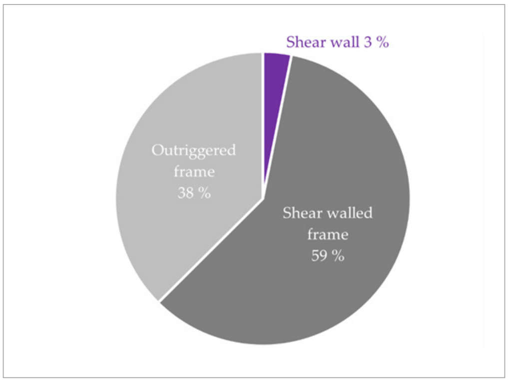


Fig. 10

Australian towers by structural system

The outriggered frame system, comprising 38% of the distribution, represents a more advanced structural solution, often implemented in taller buildings. By linking the building's central core to exterior columns, outrigger systems enhance resistance to overturning moments and lateral drift, which become critical as building heights increase (Takva et al., 2023). This system is favored for its ability to maintain a slender profile while optimizing internal space utilization.

The minimal application of standalone shear walls (3%) reflects their limited use in smaller or less complex tall buildings, where simpler structural systems suffice. Overall, this distribution underscores a strategic selection of structural solutions aimed at maximizing height, optimizing interior layouts, and enhancing resilience against environmental forces—key considerations in Australia's rapidly urbanizing cities.

Table 2 specifies findings about structural material and system, comparing Australian tall buildings with those in Asia (Ilgın, 2023b), the Middle East (Ilgın, 2024), and North America (Ilgın and Aslantamer, 2024).

Table 2

Key structural considerations in other regions

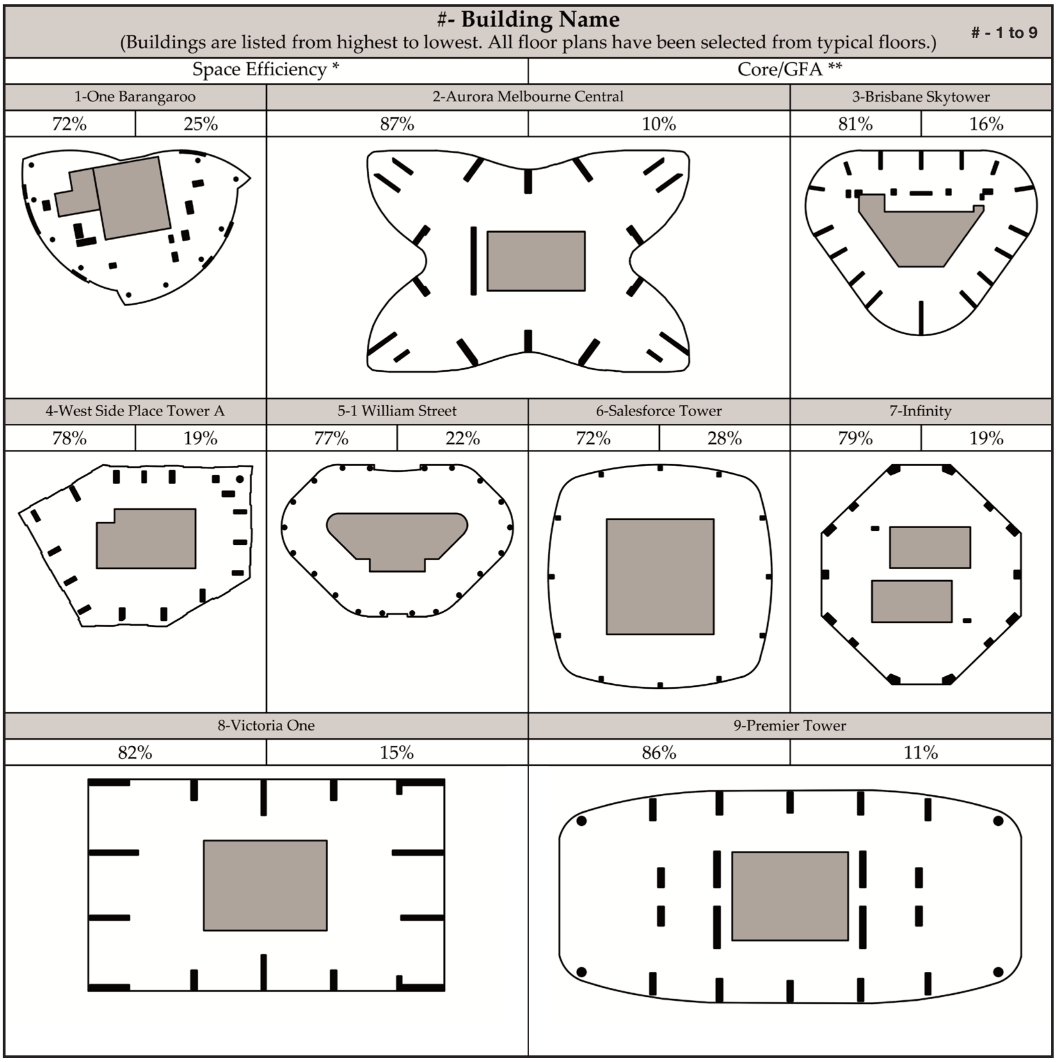
	Australia	Asia	The Middle East	Nort America
Structural material	Concrete (75%) Composite (22%) Steel (3%)	Concrete (18%) Composite (79%) Steel (3%)	Concrete (70%) Composite (30%)	Concrete (55%) Composite (39%) Steel (6%)
Structural system	Outriggered frame (38%) Shear wall (3%) Shear walled frame (59%)	Outriggered frame (76%) Tube (17%) Buttressed core (3%) Mega column & core (3%) Shear-frame (1%)	Outriggered frame (44%) Tube (26%) Buttressed core (4%) Mega column & core (15%) Shear-frame (11%)	Outriggered frame (42%) Tube (16%) Mega core (3%) Shear walled frame (39%)

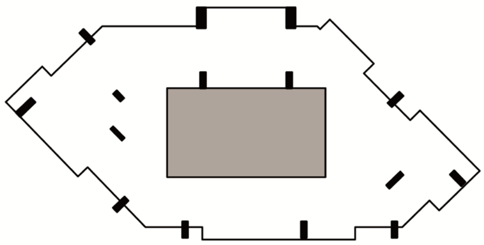
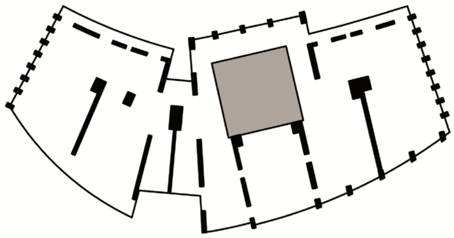
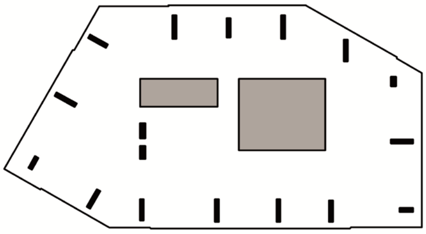
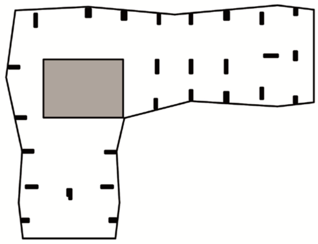
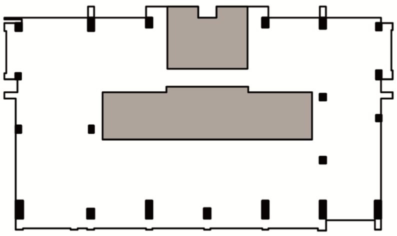
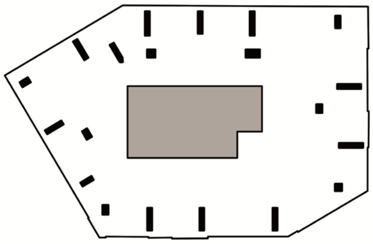
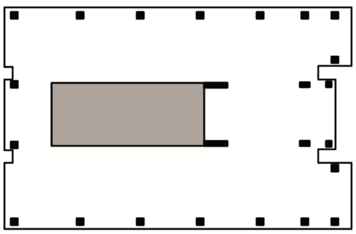
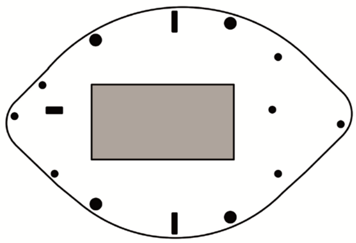
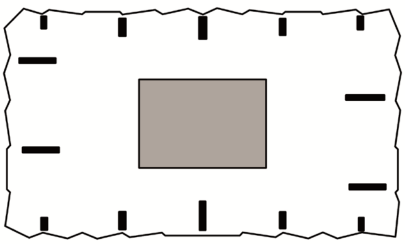
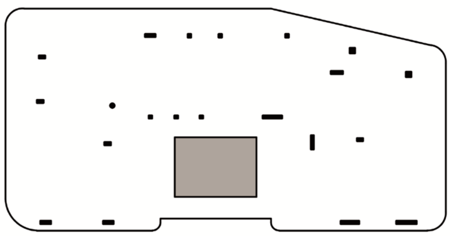
Regional tall building design varies across Australia, Asia, the Middle East, and North America (Tables 1–2), shaped by local demands, environmental conditions, and technological progress. In Australia, residential towers dominate (59%), with prismatic forms (72%) and concrete structures (75%) favored for cost-efficiency and durability. Asia emphasizes mixed-use towers (57%) with complex geometries and composite materials (79%), reflecting high density and seismic considerations. The Middle East blends residential (45%) and mixed-use (33%) towers using concrete (70%) and composite (30%) for iconic, large-scale designs. North America shows functional diversity—mixed-use (42%) and office (32%)—with a material mix of concrete (55%), composite (39%), and steel (6%), balancing tradition and innovation. These trends underscore the influence of local contexts on tall building design.

Space efficiency in Australian towers

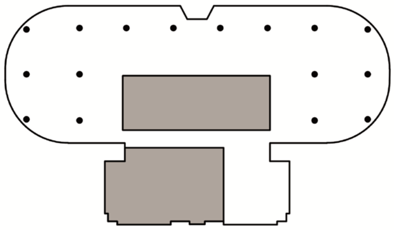
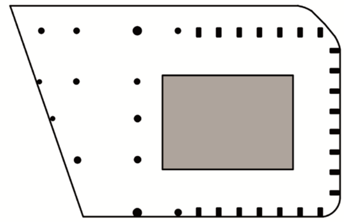
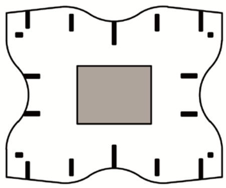
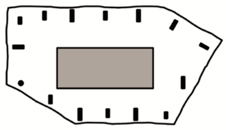
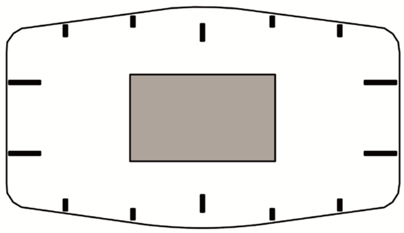
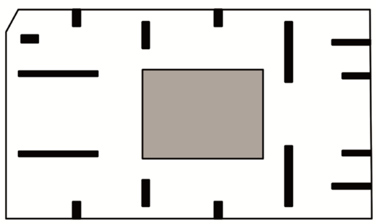
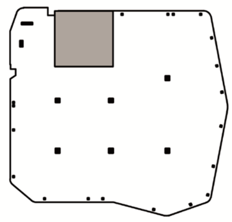
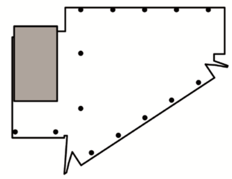
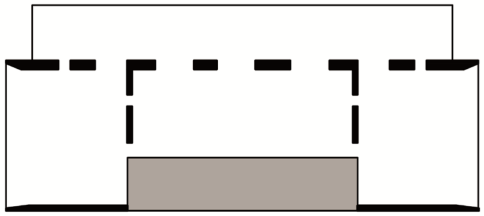
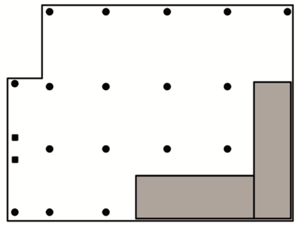
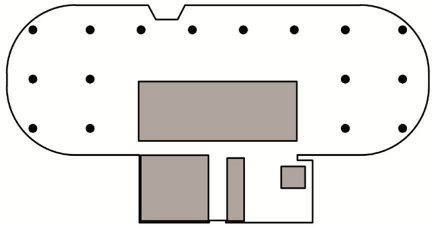
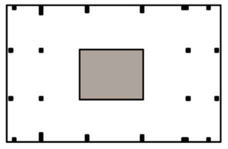
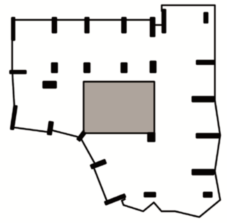
In Australian tall towers, average space efficiency was 82%, with the core occupying 16% of the GFA (Fig. 11). Observed values ranged from 72% and 5% to a maximum of 94% and 28%, respectively. Table 3 compares these findings on average space efficiency and core-to-GFA ratios with data from Asia (Ilgın, 2023b), the Middle East (Ilgın, 2024), and North America (Ilgın & Aslantamer, 2024).

Fig. 11
Space efficiency and core/GFA of Australian tall buildings



#- Building Name (Buildings are listed from highest to lowest. All floor plans have been selected from typical floors.)		**# - 10 to 19**	
Space Efficiency *		Core/GFA **	
10-Soleil		11-Soul	
79%	19%	86%	9%
			
12-West Side Place Tower D		13-Swanston Central	
88%	11%	87%	11%
			
14-The Greenland Centre		15-West Side Place Tower C	
79%	19%	85%	13%
			
16-568 Collins Street		17-Sapphire by the Gardens	
86%	13%	79%	19%
			
18-Light House		19-Victoria and Albert Residences (Tower 2)	
85%	13%	94%	5%
			

#- Building Name
(Buildings are listed from highest to lowest. All floor plans have been selected from typical floors.) **# - 20 to 32**

Building	Space Efficiency *	Core/GFA **	Floor plan
20-International Towers Sydney Tower 1	73%	26%	
21-Quay Quarter Tower	79%	20%	
22-UNO Melbourne	85%	13%	
23-West Side Place Tower B	79%	19%	
24-Eq. Tower	83%	16%	
25-Empire Melbourne	82%	14%	
26-One One One Eagle Street	92%	8%	
27-ANZ Tower	86%	13%	
28-Collins House	83%	13%	
29- 80 Collins South	82%	17%	
30-International Towers Sydney Tower 2	77%	22%	
31- MY80	88%	11%	
32- Manhattan @ Upper West Side	85%	11%	

Space Efficiency* : calculated as the ratio of the net floor area obtained by subtracting the service core (the gray area on the floor plan) and structural elements from NFA to GFA.

Core / GFA** : calculated as the ratio of the service core (the gray area on the floor plan) to GFA.

In the floor plans the gray area corresponds to service core, while black area signifies structural elements.

Table 3

Ratios of space efficiency and core to GFA in other regions

	Australia	Asia	The Middle East	North America
Average space efficiency	82% (max. 94%, min. 72%)	67.5% (max. 82%, min. 56%)	75.5% (max. 84%, min. 63%)	76% (max. 84%, min. 62%)
Average ratio of core to GFA	16% (max. 28%, min. 5%)	29.5% (max. 38%, min. 14%)	21.3% (max. 36%, min. 11%)	21% (max. 31%, min. 13%)

Victoria and Albert Residences (Tower 2), One One One Eagle Street, and MY80 exemplify advancements in architectural design and space efficiency, with spatial efficiencies ranging from 88% to 94%. These high-rises set a new benchmark for reduced GFA ratios through innovative core layouts and advanced structural systems. Vertical transportation—comprising elevators, staircases, and mechanical systems—is meticulously planned to minimize core footprint, maximizing usable space and enhancing overall functionality.

Structurally, these towers employ shear-walled frame systems, optimizing resistance to vertical and lateral forces. Compact cross-sections within structural elements efficiently distribute loads, improving stability against wind and seismic stresses. This precision in structural design ensures durability under high-rise conditions. By integrating cutting-edge architectural and engineering strategies, these towers achieve a balance between spatial optimization and structural resilience. Their efficient core configurations and material-conscious design minimize environmental impact while enhancing urban living quality. This approach establishes a model for future high-rise development, emphasizing efficiency, resilience, and sustainability in urban architecture.

Relation of Space Efficiency and Design Parameters

Fig. 12–16 analyze the relationship between spatial efficiency and key architectural and structural factors. A bar graph on the right categorizes towers by relevant classifications, organizing data distribution, while colored dots indicate spatial efficiency in relation to design parameters, offering an intuitive visualization of efficiency trends. Gray bars highlight the frequency of towers sharing similar characteristics, emphasizing dominant architectural and structural patterns.

Fig. 12 examines the correlation between space efficiency and function. Residential buildings demonstrate the highest median efficiency (~80%) with relatively low variability, indicating consistency in space utilization. Office buildings, in contrast, exhibit a lower median (~75%) with greater variability, reflecting diverse spatial requirements. Mixed-use buildings show a similar median to office buildings but display a wide range of efficiency values, emphasizing the complexity of multifunctional spaces.

This variability is linked to functional design constraints. Residential buildings prioritize habitable space with standardized layouts, whereas office and mixed-use towers integrate communal, technical, and commercial areas, reducing overall efficiency. Additionally, the smaller sample sizes for Office (n=8) and Mixed-use (n=5) buildings compared to Residential (n=19) may contribute to the observed variation, highlighting the need for further study with a larger dataset. This analysis underscores the importance of function-specific design considerations in assessing spatial efficiency, particularly in the Australian context, where regulatory and design preferences shape these outcomes.

Fig. 13 shows space efficiency variations across core configurations. Residential towers with central cores maintain high efficiency (~80% median) due to standardized layouts minimizing circulation. Office buildings with central cores show greater variation (70–90%), balancing open-plan and partitioned space. Despite structural and logistical benefits, efficiency fluctuates due to flexible layouts and tenant-driven changes. Mixed-use towers (median ~75%) exhibit similar variability, constrained by integrating residential and office functions, requiring distinct circulation and service systems.

Fig. 12
Tall towers by function

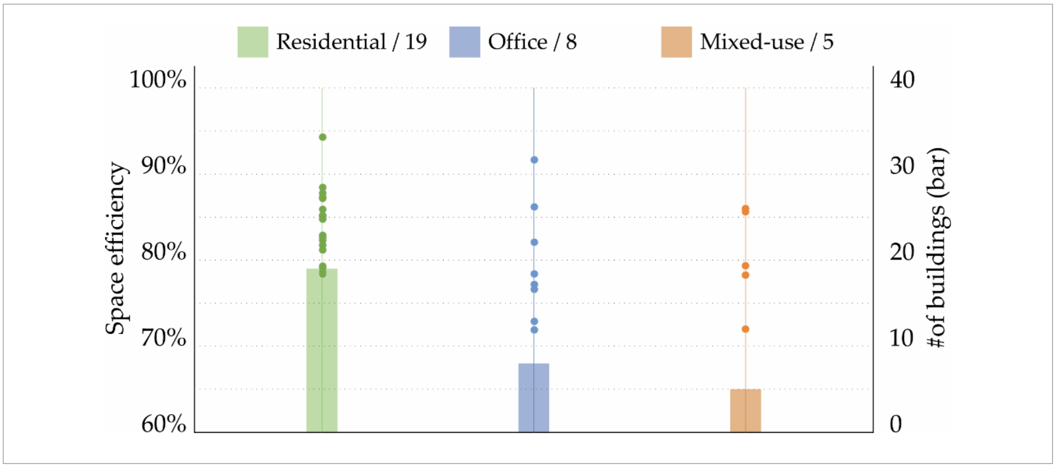
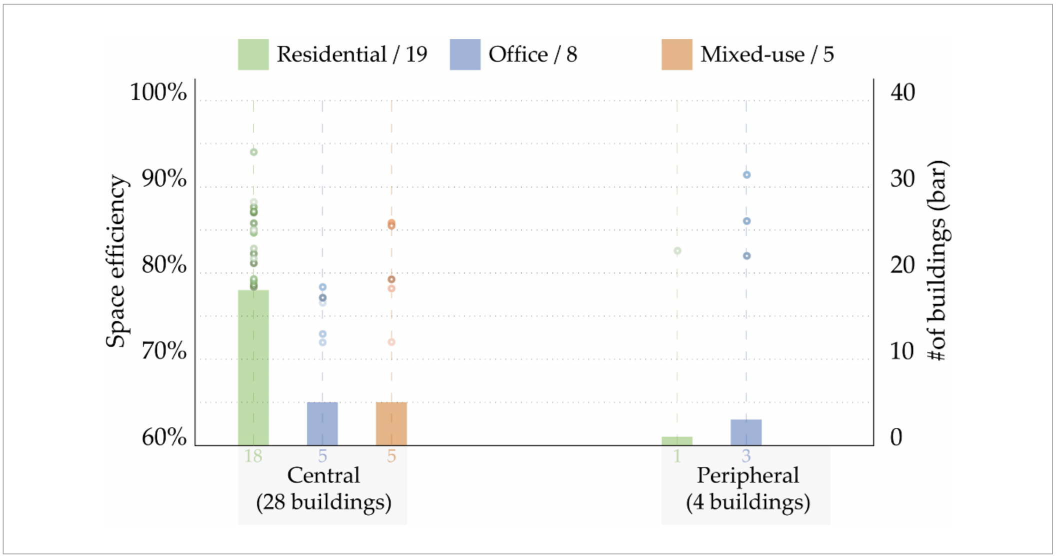


Fig. 13
Tall towers by core type



Peripheral cores present even wider efficiency ranges, especially in office buildings (60–90%), influenced by site-driven adaptations, and diverse tenant needs. While peripheral cores offer flexibility, they can reduce efficiency. Mixed-use buildings with peripheral cores face comparable challenges in accommodating multifunctionality within urban constraints. Service core size critically impacts efficiency. Compact, integrated cores in residential towers maximize usable space, while larger cores in mixed-use and office buildings, designed for high occupancy and complex functions, reduce efficiency.

Fig. 14 examines space efficiency in relation to building form. Prismatic buildings, especially residential towers, achieve higher median efficiency (~80%) due to standardized layouts that integrate cores with minimal disruption. In contrast, free-form buildings show greater variability (60–90%), reflecting challenges in balancing architectural complexity with spatial optimization, particularly in mixed-use developments requiring intricate core designs.

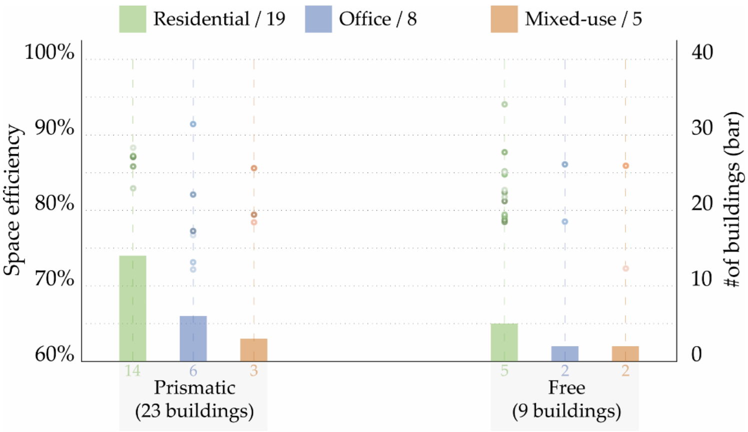


Fig. 14
Tall towers by form

Office buildings, with extensive vertical circulation and service areas, allocate more GFA to cores, resulting in lower efficiency than residential towers. These findings highlight the impact of building form on efficiency, shaped by function, core configuration, and structural constraints. The variability in free-form and mixed-use buildings underscores the trade-offs between aesthetic ambitions and operational requirements.

Fig. 15 analyzes space efficiency in relation to structural materials—steel, concrete, and composite—in tall buildings. A single steel office tower records ~70% efficiency, offering a preliminary benchmark but insufficient for broad conclusions.

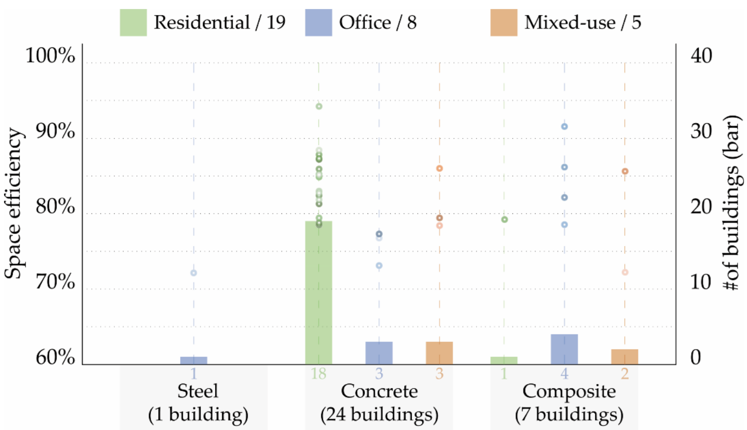


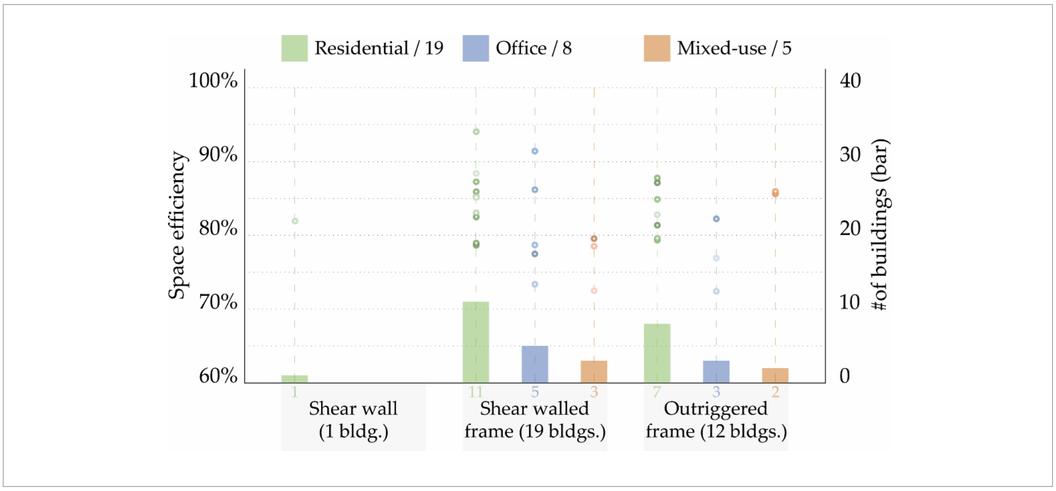
Fig. 15
Tall towers by material

Concrete, the most prevalent material (25 buildings), achieves a median ~80% efficiency in residential towers, with a narrow distribution, indicating effective space utilization. However, concrete office and mixed-use buildings display wider efficiency variation (60–90%), shaped by functional and design complexities. Composite structures (7 buildings) also show a broad efficiency range (60–90%), reflecting diverse hybrid design approaches. Despite limited data on steel and composite buildings, findings emphasize concrete's dominance in ensuring consistent efficiency, particularly in residentials.

Fig. 16 examines the impact of structural systems on space efficiency in tall buildings, comparing shear wall, shear-walled frame, and outriggered frame systems. A single shear wall residential tower (~80% efficiency) provides a reference point but lacks broader data. The shear-walled frame system (19 buildings) shows a median ~80% efficiency in residential towers, with greater variability in office and mixed-use buildings (60–90%), highlighting its reliability for residences but dependence on design complexities in other functions.

Fig. 16

Tall towers by structural system



The outriggered frame system (13 buildings) exhibits the widest efficiency range, with slightly lower median efficiency in residential towers than shear-walled frames. This system's architectural flexibility enables diverse designs but can reduce space optimization. In office and mixed-use buildings, efficiency ranges from 60% to 90%, reflecting the challenge of balancing adaptability and efficiency.

Discussion

This study analyzes architectural and structural factors affecting space efficiency in Australian tall buildings through 32 case studies. Key strategies include central cores, prismatic forms, shear-walled frames, and composite materials to enhance efficiency.

By quantifying spatial efficiency and core-to-GFA ratios, it establishes critical benchmarks—82% efficiency and a 16% core-to-GFA ratio—guiding future skyscraper designs. These findings offer practical insights for architects and engineers, promoting economic efficiency and sustainability amid rising urban density and land costs. Australian high-rises predominantly feature central cores, maximizing perimeter usability, daylight access, fire safety, and structural flexibility (Kim et al., 2022). Unlike tapered Asian (Ilgın, 2023b) and setback North American towers (Ilgın & Aslantamer, 2024), Australian designs favor prismatic forms, mirroring Middle Eastern trends (Ilgın, 2024) due to their geometric efficiency and streamlined construction. Concrete dominates Australian high-rise construction, aligning with Middle Eastern and North American trends (Ilgın, 2024; Ilgın & Aslantamer, 2024). Its durability, fire resistance, and adaptability—especially when reinforced with steel—ensure optimal structural performance. Shear-walled frames, prevalent in Australia and Turkey (Aslantamer & Ilgın, 2024), surpass outriggered frames, which are common in Asia, the Middle East, and North America. Their high lateral resistance enhances stability, minimizes sway, and ensures regulatory compliance. Globally, high-rise efficiency averages 75% (Yeang, 2000), with variations across Asia (67.5%), the Middle East (75.5%), and North America (76%) (Ilgın, 2023b; Ilgın, 2024; Ilgın & Aslantamer, 2024). Timber high-rises, notably in Finland, reach 83–88% (Lee et al., 2022; Ilgın et al., 2021; Karjalainen et al., 2021). Australian towers achieve an 82% average efficiency with core-to-GFA ratios of 16%, ranging from 72–94%

and 5–28%, respectively. Their superior efficiency is driven by optimized core footprints enabled by advanced materials and structural innovations. To enhance efficiency, architects should: Favor prismatic forms to simplify construction and maximize usable space; Adopt central cores for better daylighting and reduced circulation space; Utilize advanced materials, such as graphene-reinforced concrete and composite steel-concrete systems, for optimized core design; Leverage parametric design tools to refine core placement and building form; and Encourage interdisciplinary collaboration to align design strategies with sustainability goals. The established benchmarks—82% efficiency and a 16% core-to-GFA ratio—support: Architects, in designing efficient, cohesive high-rises; Developers, in maximizing leasable areas and profitability; Policymakers, in integrating efficiency-driven standards into urban planning.

In the Australian metropolitan context, tall buildings are typically positioned within high-density urban centers, such as Sydney's Central Business District (CBD), Melbourne's Southbank precinct, Brisbane's Queen's Wharf, and the Broadbeach area of the Gold Coast. These locations are characterized by limited land availability, high land values, and intense development pressure, leading to vertical densification as a primary strategy for accommodating population and commercial growth. Within these districts, tall buildings are rarely isolated; instead, they form cohesive vertical clusters—sometimes referred to as "vertical neighborhoods"—which require careful spatial coordination. Local planning instruments, such as Sydney's Central Sydney Planning Strategy and Melbourne's Urban Design Frameworks, set regulations for minimum tower separation distances, solar access corridors, pedestrian-level wind mitigation, and view sharing, all of which directly affect how tall buildings relate to their surroundings. Although our study does not include a quantitative analysis of inter-building distances or site layout patterns, we acknowledge that these urban morphological dimensions significantly influence not only microclimatic conditions and public realm quality but also the perceived and actual efficiency of space use in the broader urban tissue.

As emphasized by Lehmann (2017) and Al-Kodmany (2018), the effective integration of tall buildings into compact urban environments hinges on holistic spatial strategies that reconcile vertical growth with human-scale design principles. This includes the provision of street-level amenities, visual permeability, green infrastructure, and transitional massing to minimize adverse effects such as urban canyons, wind tunnels, and loss of daylight. While our current research remains focused on internal spatial efficiency—specifically NFA utilization and core planning efficiency—we acknowledge that external spatial logics, including sky view factor, solar envelope compliance, and active frontages, are integral to achieving sustainability and livability outcomes in tall building districts. Future research could thus benefit from combining internal metrics with external urban integration parameters to develop a multi-scalar evaluation framework for tall building performance.

While this study demonstrates that tall buildings in Australia exhibit high levels of internal spatial efficiency—averaging 82% NFA-to-GFA and 16% core-to-GFA ratios—it is important to recognize that spatial efficiency does not necessarily equate to overall building efficiency. Several studies highlight the potential drawbacks of tall buildings that may offset their spatial optimization. For instance, Kim and Elnimeiri (2004) emphasize that rigid core placements and deep floorplates can reduce adaptability over time, limiting functional flexibility. Similarly, Yeang (2000) and Sharma & Mistry (2023) note that tall buildings tend to have higher energy demands due to intensive elevator use, HVAC load, and larger facade surface-to-volume ratios, which can reduce operational sustainability. Lehmann (2017) also critiques the evacuation and circulation inefficiencies in high-rises, especially under emergency conditions, which may impact usable space indirectly. Furthermore, Le et al. (2018) raise concerns about the embodied carbon and lifecycle impacts of tall buildings—particularly those constructed primarily with reinforced concrete. These arguments suggest that while internal spatial ratios offer valuable insight, they should be interpreted within a broader performance framework that includes adaptability, energy efficiency, and lifecycle considerations.

These findings offer practical insights for architects, engineers, and urban planners by identifying design strategies—such as central core planning and prismatic forms—that consistently achieve higher space efficiency in dense urban contexts. However, these same strategies may introduce trade-offs. For instance, prismatic forms, while construction-friendly, may limit façade design flexibility and reduce architectural expression. Similarly, central cores can optimize circulation and daylight access but may hinder future spatial reconfiguration, particularly in mixed-use or adaptive reuse scenarios. Despite these trade-offs, the ability to benchmark core-to-GFA ratios and NFA efficiency provides a valuable reference for professionals seeking to maximize floorplate usability under high land cost conditions. The study's contribution is also novel in its application of standardized metrics across a national sample of tall buildings—something rarely done in the Australian context—thus offering both academic and professional utility for future vertical development models.

Future research should explore: Next-generation materials, including graphene-reinforced concrete and carbon fiber composites; AI-driven parametric design to optimize core layouts; Long-term performance metrics, including energy use, maintenance costs, and occupant well-being; Urban densification policies and their impact on efficiency and regulatory frameworks; Comparative studies across residential, office, and mixed-use towers; Social implications, such as housing affordability and livability. Key limitations include: A small sample size (32 towers), limiting generalizability; Focus on contemporary buildings, excluding historical trends; Australia-specific findings, which may not directly apply to other regions; Core-to-GFA ratio as the primary metric, without factoring adaptability or long-term operational performance; Limited analysis of socioeconomic and environmental impacts.

This study establishes crucial benchmarks for high-rise efficiency, highlighting the role of advanced core layouts, materials, and parametric design in optimizing skyscraper development. The findings offer a foundation for future research and a practical framework for creating more efficient, resilient, and sustainable tall buildings.

Conclusions

This study set out to investigate how architectural and structural parameters influence internal space efficiency in tall buildings, using a sample of 32 Australian towers. The findings show that strategies such as centrally located cores, prismatic forms, and reinforced concrete frames consistently support higher NFA/GFA ratios—averaging 82%—and relatively low core-to-GFA ratios of around 16%. These empirical insights contribute to the underexplored literature on high-rise spatial performance in the Australian context and offer a benchmark for future design evaluations.

The practical implications of these findings are significant: architects and developers working in dense urban environments can use this evidence to make design choices that enhance leasable floor area, improve circulation efficiency, and align with cost and regulatory constraints. From a policy perspective, the results support planning standards that prioritize compact core design and simplified forms without compromising safety or livability.

While the study provides original empirical data and comparative analysis, its limitations include a relatively small sample size and a focus on internal spatial metrics only. Future research should explore how these strategies interact with energy use, environmental performance, and post-occupancy adaptability—especially in the context of AI-driven parametric design and advanced material systems. The investigation of space efficiency in Australian timber high-rise buildings could also represent a valuable direction for future research.

By linking empirical analysis with design practice and theoretical frameworks, this research strengthens the understanding of space efficiency in tall buildings and provides a foundation for future urban and architectural innovation.

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About the authors

HÜSEYİN EMRE ILGIN

Postdoctoral research fellow

School of Architecture, Faculty of Built Environment, Tampere University, Tampere, Finland

Main research area

Tall building design, wood construction

Address

School of Architecture, Faculty of Built Environment, Tampere University, Tampere, Finland
E-mail: emre.ilgin@tuni.fi

ÖZLEM NUR ASLANTAMER

Instructor Dr

Department of Interior Architecture and Environmental Design, Faculty of Art, Design and Architecture, Atılım University, Ankara, Turkey

Main research area

Interior Space Planning & Design, Public Space Design, Modular Design, Efficiency in Design, CAD, BIM wood construction

Address

Department of Interior Architecture and Environmental Design, Faculty of Art, Design and Architecture, Atılım University, Ankara
E-mail: ozlem.aslantamer@atilim.edu.tr