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The Vertical City Paradigm as Sustainable Response to Urban Densification and Energy Challenges: Case Studies from Asian Megacities

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Abstract

Due to rapid economic development, high energy consumption, and the depletion of natural resources, resulting in climate change, urban planners and architects face the difficult task of creating a new type of sustainable city that takes into account rapid population growth. The aim of this article is to examine the development of contemporary forms of high-rise architecture and the role of the vertical city in responding to shrinking space and developing a realistic strategy for sustainable urban development. Literature analysis, case studies, and multidisciplinary analysis are used. Pro-ecological solutions are identified and analyzed using the most representative buildings in Asia and a theoretical example in Nanjing. The examples are characterized by above-average height, unusual shapes, and the use of advanced pro-ecological strategies. Greenery plays a key role, including regulating the temperature inside the building. Vertical multifunctionality is becoming an increasingly common response to increasing spatial needs. The apparent lack of understanding of the development of high-rise buildings in cities around the world, extending beyond individual skyscrapers, constitutes a research gap. This article discusses Chongqing, an example of a vertical city, which is understood not only in terms of individual high-rise buildings but also as a whole structure. The study addresses the issue of a new type of compact city: the vertical city. The article provides key guidelines and constraints for creating densely populated, yet sustainable and environmentally friendly cities of the future. The practical application of the study can be utilized by urban planners and decision-makers.

Keywords: architecture; vertical city; urban sprawl; sustainable energy; skyscrapers

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1. Introduction

Modern cities face enormous challenges related to the increasing effects of climate change and rapid population growth. Currently, over 55% of the population lives in cities, and according to predictions, by 2050 this percentage will increase to 68%. It is assumed that 90% of the urban population growth will occur in Asia and Africa (especially in India and China) [1]. It is becoming necessary to create urban structures that combine high development intensity with respect for the environment and social needs. Over the last two decades, high-rise buildings have experienced a global boom and are becoming a new

global phenomenon [2]. This trend is clearly visible in the contemporary architectural and urban development of China. The city of the 21st century is becoming increasingly vertical, and high-rise buildings are starting to become a major architectural and urban issue and an important point of sustainable design. It is noticed that such elements contribute to giving the building a distinct identity and make it a recognizable observation point [3]. At the same time, in many cities in developing countries, iconic buildings constitute an individual image among the world's metropolitan groups. 21st century metropolises often compete for dominance at many different scales, which is why high-rise buildings are designed to be a showcase for a given country [4]. With the rapid development of the economy, more and more tall buildings appear [5]. In 2017, 144 buildings were constructed in the world that were 200 m high or more, 50% of which were located in China [6]. China now accounts for 21% of the world's population, so its per capita and energy consumption has a global impact and is attracting worldwide attention. Over the past three decades, urbanization has occurred even faster than population growth. In the process, high energy consumption, high pollution rates, loss of biodiversity, and deteriorating water quality have all been visible. Research in China since the 1980s has made impressive progress, and the country is now increasingly focused on creating an ecological civilization [7]. China has committed to achieving carbon neutrality by 2060 [8]. The spread of urban forms across the landscape, and the slowing of this process, has become a key element of planning tools.

Many scientists have raised concerns about tall buildings as a type of unsustainable building. In the 1970s, Christopher Alexander, in his book "A Pattern Language," completely rejected the tall city as a viable human habitat [9,10]. Léon Krier, a supporter of this urbanism movement, emphasized in his book "The Architecture of Community" that buildings should not be more than five stories high [11]. However, nowadays, due to dynamic development, vertical cities are becoming a reality and not just a theory. In places where land prices are high and space is limited, urban planners and architects are increasing their focus on designing vertically [12]. Brian Webb highlights a clear research gap in the lack of understanding of high-rise development in cities worldwide, extending beyond individual skyscrapers to provide deeper analysis and connections with the surrounding development [13]. Steve Frolking's research points to a shift from lateral urban expansion to more vertical urban development. This phenomenon occurred to varying degrees and in different decades, depending on the country. However, the greatest increases in growth rates were observed in Asian cities [14]. Urban growth is causing environmental and social problems. New urban greening concepts are being developed to mitigate these problems in a sustainable manner. Vertical greening systems are gaining popularity [15], but there is a lack of adequate publications on the development of vertical green spaces in high-rise buildings. This study highlights the contribution of this new, expanding form of 21st-century development to sustainable urban development.

The aim of this article is to examine how contemporary forms of high-rise architecture oriented towards sustainable development are developing in key metropolises in Asia, and what is the role of the vertical city in response to shrinking space. Particular emphasis was placed on identifying and analyzing pro-ecological solutions in high-rise buildings, including the local certification system: the China Green Building Evaluation Label (China Three Star). This document was developed in 2006 by the Ministry of Housing and Urban–Rural Development of the People's Republic of China. This certification identifies a green building as one that maximizes energy, space, water, and material savings throughout its lifecycle, and in which environmental protection and human health protection, as well as efficient use of space and harmonious coexistence with the natural environment, are incorporated into the design. This study identifies a gap and expands existing knowledge on certification with the China Green Building Evaluation Label system, which is rarely

addressed in the available literature due to limited language accessibility. Existing publications primarily refer to the most popular green building certification systems, such as BREEAM, LEED, and DGNB. The study demonstrates the need to expand the analysis of the vertical city paradigm, as most buildings are currently treated on a point-based basis. This article clearly highlights Chonging as an example of a fully vertical city, which could become a benchmark for other cities. This perspective has often been overlooked until now. Comprehensive research on the development of vertical cities is lacking, and this article is an original contribution to the topic. Unlike previous studies, this article contributes to the theory of the pro-ecological vertical city and offers a different perspective on the urban and architectural development of megacities that will develop in the coming decades of the 21st century. Moreover, it diagnoses emerging socio-demographic, ecological and economic problems. The research questions were: Is the vertical city a contemporary alternative to the compact city and the postulates of the Athens Charter? What key elements should urban planners and architects pay attention to when designing densely populated, yet sustainable and environmentally friendly cities of the future in the era of consumerism and global warming? The methods used allow for a multi-faceted approach to the topic—both from a theoretical and practical perspective. The article presents a broader theoretical context, indicating the potential of high-rise buildings as carriers of new urbanism of the future. This study contributes to expanding the existing knowledge on the vertical cities' paradigm and also points to the need for a multidisciplinary approach to the design of contemporary architectural and urban forms.

2. Materials and Methods

The article uses terminology analysis to understand key terms and case studies, which discuss the following examples: Shanghai and Shangahi Tower (Shanghai, China), Marina One (Singapore), Qianhai and KingKey 100 (Shenzhen, China), Raffles City (Chongqing, China), the unrealized Nanjing Vertical Forest Towers project (Nanjing, China), CITIC Tower (Beijing, China), Guangzhou Chow Tai Fook Finance Center (Guangzhou) and Shenzhen Ping An Finance Center. The selection criteria were thematic representativeness, innovation, significance of the objects and their accessibility, as well as comparative potential in order to understand contemporary urban and architectural trends in Asian cities.

Architectural, ecological, and urban design elements were incorporated into the analysis through the use of consistent evaluation criteria, enabling transparent and repeatable comparisons across case studies. Each building was analyzed based on three main groups of indicators: architectural criteria (building form, function, integration with the surroundings, and human scale), ecological criteria (the use of pro-ecological technologies, energy- and water-saving systems, greenery integrated into the building, and environmental impact), and urban design criteria (location within the city structure, accessibility, relationships with public space, and role in the development of compact, sustainable urban development). This approach allows for a systematic comparison of the buildings and facilitates the identification of each building's strengths and weaknesses. Section 4 contains a discussion, divided into subsections: green building certification, greenery, multifunctionality, communication accessibility, landmark and observation point, threats, main challenges and development directions. The discussion section includes an illustration identifying key design issues organized into three categories: people—environment—high-rise building. By using consistent criteria and visually presenting the results, the analysis maintains methodological consistency, and its process is transparent and reproducible in future research. Figure 1 illustrates the methodology adopted in the article.

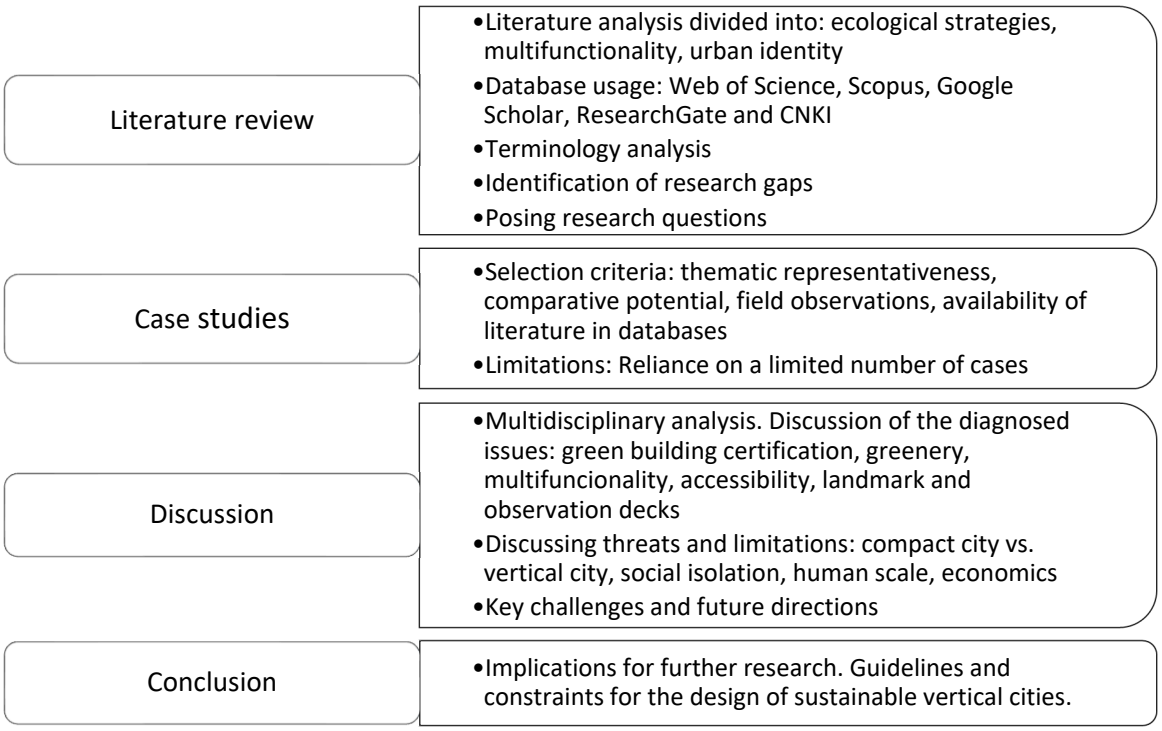


Figure 1. Diagram of the adopted methodology. Source: Own elaboration.

A key element of the research process was field observation conducted by the authors, which included study visits to selected districts of Shanghai, such as Lujiazui (Pudong—the financial center filled with skyscrapers) and Huangpu (with the Bund—a riverside boulevard that served as a center of commerce during the colonial era), as well as to the cities of Chongqing and Beijing. The authors had the opportunity to experience the urban context firsthand and observe architectural solutions in situ. The collected empirical data was supplemented with photographic documentation. The adopted time frame covers the years 2010–2025 and is related to Frolking's research, which showed a global trend of vertical city development in the years 2010–2021. The greatest increase in the pace was recorded in Asian countries and is related to changes in the amount of material and energy consumption, the way of life in the city and the local climate [14]. The criterion for selecting the city of Chongqing was that it is a key example of the importance of vertical urbanism in a Chinese city [16], constituting another research gap in the issue of the vertical city paradigm. Another method was a literature review. The search engines used included the following databases: Web of Science, Scopus, Google Scholar, ResearchGate and CNKI (China National Knowledge Infrastructure). The article also includes elements of the hermeneutic method in order to understand the architectural symbolism and social reception of buildings. The research approach was interdisciplinary—it combined elements of the theory of architecture, urban planning, pro-ecological issues and the analysis of urbanized space.

3. Results

3.1. Literature Review

3.1.1. Ecological Strategies

The publication of the Brundtland Commission Report was a precursor to the United Nations Conference on Sustainable Development (1992) in Rio de Janeiro, and both events played a fundamental role in global initiatives for sustainable development. The term came to be associated with all human interventions on planet Earth, and the construction

industry was recognized as a significant factor in its impact on society, the environment, and the economy [17]. Sustainable construction involves reducing the negative impact on the environment while improving the quality of life, and its aim is to optimize the building's parameters, taking into account environmental, economic and social aspects [18]. Climate change and rapid urbanization are a very important problem, as approximately 56% of the world's population lives in urban areas [19]. In recent years, there has been a growing interest in developing effective solutions that improve the long-term energy efficiency of buildings, and the use of greenery on facades as an element of improving the quality of life is becoming increasingly popular [20]. The vertical dimension is a key, yet often overlooked, element of urban landscape research [21]. Vertical space is becoming increasingly colonized, as evidenced by the growing number of high-rise buildings. Although central business districts (CBDs) were established as early as the 1960s, since the mid-1990s, an explosion of verticality has been noticeable in cities around the world. Urban planning theorists have also begun to pay attention to the third spatial dimension: height [22]. Kheir Al-Kodmany emphasizes that the 21st century is witnessing the development of a new generation of high-rise buildings that incorporate ecological design elements, including aerodynamic shapes, energy-saving systems, the use of renewable energy, rainwater conservation and harvesting technologies, and the use of greenery [3]. Solar energy has become a significant factor contributing to the rapid spread of renewable energy and its use in residential and commercial construction has brought significant benefits [23]. Building Information Modeling (BIM) and thermal imaging from drones are modern, innovative technologies used to improve the energy efficiency of buildings throughout their entire life cycle [24]. There is little research focusing on the application of the UN Sustainable Development Goals in shaping smart vertical cities [25]. In high-density cities, the surface area of buildings' walls is significantly larger than the surface area of roofs and ground, offering a vast platform for greening. There is scientific evidence supporting the thermal benefits of this design option [26].

3.1.2. Multifunctionality

Once population density reaches a certain level, verticality becomes a key element. Historically, all elements, such as streets, open spaces, green spaces, and land use, are rearranged and undergo mutations. Some megacities, such as Shanghai, Hong Kong, Tokyo, and Seoul, have areas where the density index exceeds 12 and the population density exceeds 400 people per acre. In such cities, all infrastructure must be integrated into a system extending both below and above the vertical space. Therefore, vertical cities are characterized by a third dimension [27]. The development of metropolises, primarily in Asian countries, is fueled by a thriving real estate market. Martinez Munoz, Adrian, considers the city as a multi-layered and multi-dimensional urban organism, shaped vertically, as an alternative to designing according to the principles of the Athens Charter published in 1931 [28]. Helen Barrie's case study of U City in Adelaide [29] focuses on a highly mixed-use high-rise building that houses retirement homes, accommodation for people with disabilities, services for vulnerable populations, commercial tenants, retail outlets, and conference rooms. Additionally, public spaces were designed to foster positive emotions and a sense of belonging among diverse groups of residents, workers, and occasional users. The findings demonstrate that the design and operation of public spaces can connect diverse user groups.

3.1.3. Urban Identity

A sense of place, as an intangible perception, is considered an element of urban identity. Its value is emphasized in cross-cultural research and urban planning [30]. Local

culture, customs and traditions are considered to be elements that shape the character of the space [31]. Contemporary trends such as globalization and the resulting uniformity contribute to the loss of identity of urban areas [32]. In the psychological aspect, identity is considered as a specific manifestation of collective or individual self-awareness. Shahammaymon, G, points out that scholars have widely discussed the fragmentation of national identity among individuals in a globalized world, and also emphasizes that cities are becoming arenas for the cultivation of communal belonging and identity [33]. The shaping of urban features depends largely on the context, and architectural features, often including a distinct style, are important elements of protecting and nurturing identity [34].

3.2. Terminology Analysis

There is a noticeable increase in interest among planners and architects in the paradigm of the vertical city. The rapidly growing population and the phenomenon of urban expansion force the concentration of the city vertically, as an alternative to urban sprawl [2]. Height is the main defining feature of a vertical city and is related to many factors: environmental (including atmospheric factors), aviation, vertical communication (elevators), fire safety and structural efficiency [35]. In the existing literature, high-rise buildings are mainly discussed as individual architectural works or elements in a historical context [36]. Kheir Al-Kodmany points out that there is no universally accepted definition of a tall building. For example, German regulations define it as a building taller than 22 m, while the ASHRAE Committee for Tall Buildings defines it as taller than 91 m [9]. According to the building classification developed by CTBUH Height Criteria for Measuring & Defining, Megatall is a tall building 600 m or taller. Vertical Cities are ultra-tall, often densely built, self-sufficient structures that function like miniature cities. The analysis of the literature revealed a research gap in defining and explaining the concept of a vertical city. Multifunctional aims to intertwine or combine different functions, resulting in more efficient use of limited space [37]. The most important document concerning sustainable development was adopted at the initiative of the UN in 1992 at the 2nd Conference in Rio de Janeiro. According to the provisions, natural resources should be protected and managed in such a way as to ensure lasting and sustainable development. In recent decades, there has been a clear increase in interest in pro-ecological construction and the use of multi-criteria certification of buildings is becoming increasingly common, constituting a method of assessing sustainable architecture and a project management tool [38]. Urban heat Island (UHI) refers to higher temperature levels in cities than in surrounding rural areas [39]. As Nakhapakorn et al. point out, the rapid growth of urbanization and population, coupled with Bangkok's limited area, has increased the need for vertical urban development. This has also led to the emergence of so-called hot spots [40]. Carbon Footprint (CF) is a specific type of environmental footprint that measures the impact of humans on the environment. It is the total of our greenhouse gas emissions [41].

3.3. Case Studies

3.3.1. Shanghai and Shanghai Tower

Shanghai has a unique geographical location and diverse culture and is one of the most dynamic cities in Asia. Over a thousand years ago, it was a fishing village, and in the 1950s and 1960s, Shanghai became an important industrial center. Shanghai is a case of a city that has undergone a transformation of environmental policy, including waste management, since 2000 to create a perspective of a healthy space [42]. It is now a mega city with a permanent population of 24.87 million in 2020. Various global trends are visible here, such as: high-rise expansion, multifunctional buildings and the growing importance of pro-ecological design. Shanghai's status as an international financial center is becoming

stronger and recognized by the world's economic circles. In 2011, the Shanghai–Beijing high-speed railway line was launched in the city, where high-speed trains run. Pudong International Airport is served by a high-speed Maglev train, reaching a speed of 431 km/h, making it the fastest commercial train in the world.

The Shanghai Tower (Figure 2a) is one of three world-class skyscrapers located in Shanghai's Lujiaziu district. It is located in one of the world's most famous financial and commercial centers, Pudong (Figure 2b). Strategically located at the mouth of the Yangtze River, the building is a symbol of modern urban development [43]. It was designed by Architectural Design & Research Institute of Tongji University (Group) Co., Ltd. and completed in 2015. Its total height is 632 m, making it the tallest building in China and the third tallest building in the world [44]. Its construction was aimed at improving the city's image and creating a point of international competitiveness [45]. Due to its incredible height and twisting shape, designers had to consider issues of lateral wind loads and building vibrations related to user comfort [46]. In 2017, research was carried out to investigate wind characteristics and their impact on buildings, in order to provide useful information for the design of wind-resistant buildings over 600 m high. In addition, natural frequency data was analyzed [47]. The building combines office, hotel, conference and exhibition functions grouped into "vertical districts". The gardens there contribute to the sense of community and also: in summer—they absorb heat from the interior of the building, in winter—they help to heat it [42]. One of the inspirations was traditional hutongs, where the people of Shanghai or Beijing live in small apartments organized around a common space. Shanghai Tower has a LEED Gold certificate and has become a reference point for green buildings. The project uses, among other things, double-glazed curtain walls (improving energy efficiency), heat pumps and a rainwater collection system (which is particularly important when rainfall is heavy, averaging around 1200 mm per year) [45].



(**a**) (**b**)

Figure 2. (**a**) Shanghai Tower in Shanghai, 2024. (**b**) View from the Bund towards Pudong—the business center of Shanghai, 2024. Source: Anna Piętocha.

3.3.2. Marina One (Singapore)

According to UN data, in 2020, Singapore was the third most densely populated territory in the world. Its population density was 7810 people per square meter. A distinctive feature is that its urbanization is mainly along the southern coast [48]. Marina One is an icon of sustainable high-rise development in a tropical climate. The project was

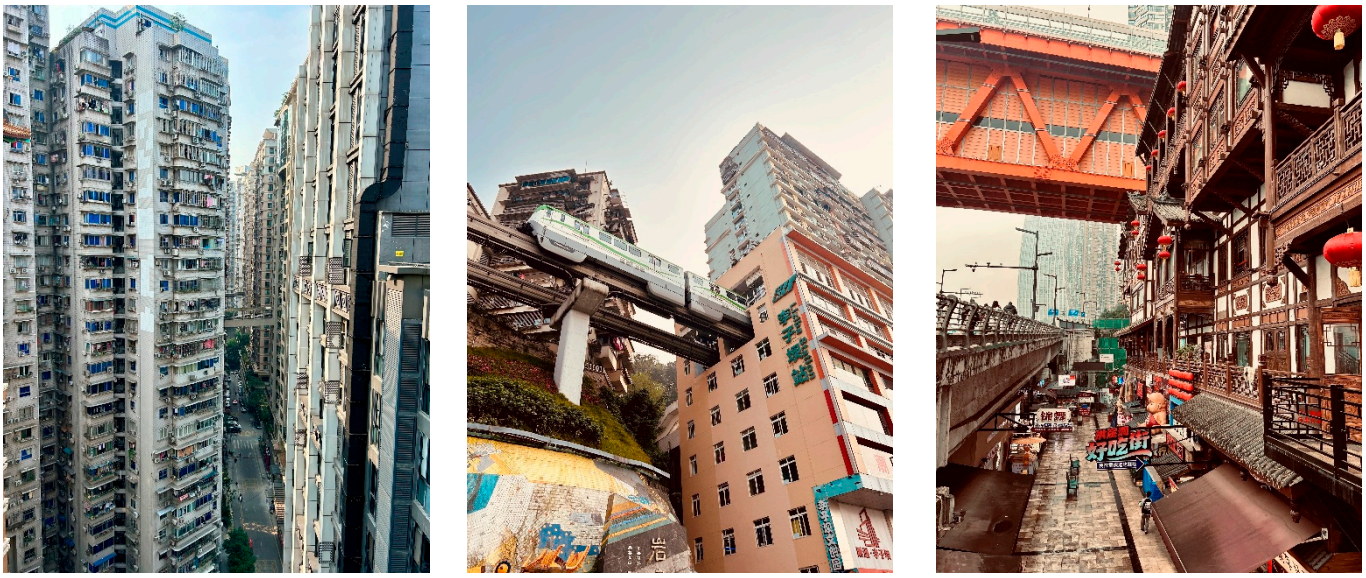
created by the Ingenhoven architectural studio in collaboration with landscape architects Gustafson Porter + Bowman. It was implemented in 2018 on 400,000 m^2. It consists of four tall buildings that house office, residential and commercial functions [49]. The office towers have a usable area of 175,000 m^2 each, while the residential towers provide 1042 apartments for around 3000 residents. The centerpiece of the development is an internal tropical garden with an area of over 37,000 m^2, called "Green Heart" by the designers—this is a public space stretching over several floors [50]. There are over 350 different species of trees and other plants. The interaction between the building masses and the garden facilitates ventilation. Singapore's Sky Gardens provide an alternative public space to compensate for the lack of public space and natural environment [48]. Organic shapes, iconic louvres and rich vegetation contribute to improving the climate and increasing biodiversity. Part of the biodiversity are numerous animal species. The design inspiration comes from Asian rice fields. The architecture imitates a green valley with its climate changes, different depending on the level. The concept is characterized by multifunctionality; there are cafes, restaurants, shops, a fitness club, swimming pool, gym, food court and supermarket. At the same time, settings for social interaction have also been created. Direct connection to rapid urban transport lines as well as numerous bus stops, bicycle parking and electric vehicle charging stations contribute to a significant reduction in exhaust fumes. Marina One is LEED Platinum certified. In accordance with the Green Mark requirements, all buildings in Singapore must meet the minimum standards specified in the criteria [51]. The project received three awards: The Asia Pacific Property Awards 2012 for: Best High-Rise Architecture, Best Mixed-use Architecture and Best Mixed-use Development.

3.3.3. Raffles City (Chongqing)

Since 1997, Chongqing has been one of the four urban centers in China (along with Beijing, Shanghai, and Tianjin) and one of the fastest-growing cities in the world [52]. A characteristic feature is the mountainous topography, which significantly influences the spatial layout, architecture and infrastructure, as well as development along the rivers. Many buildings have entrances at different levels, and communication takes place both vertically and horizontally. Urban studies have long relied primarily on a flat concept, neglecting the third dimension. Chongqing is an example of a city that extends the understanding of verticality beyond tall buildings. Located in the mountainous southwestern region of China, the metropolis (with a population exceeding 10 million in the city center and 32 million in the rural district) experiences verticality at the level of urban planning, urban management strategies, and residents' daily experiences [53]. The urban structure of this densely populated metropolis, divided by rivers and mountains, is connected by numerous bridges, tunnels, cable cars, escalators, and elevators. Elevators have entrances from streets located at different levels, while stairwells often serve public functions. The history of the city is about 3000 years old [54], although Chongqing has experienced rapid urban expansion since the 1990s and is now characterized by many unusual instances of extreme vertical building density [16]. Figure 3 shows the most characteristic spaces of Chongqing city.

Raffles City (Figure 4a) designed by Safdie Architects in Chongqing is a vibrant complex with office, residential, hotel and service functions consisting of six towers. The two higher structures are 350 m high, while the four lower ones are 250 m high. The development covers an area of 22.7 acres in the densely built-up Yuzhong district at the confluence of the Yangtze and Jialing rivers. This area was a historically important place—the city gate—and was also the most important riverside trading point. Behind the complex are two levels of city squares from which one can admire the panorama of the city.

The concept consists of vertical districts, livable urban communities and well-thought-out public spaces. Slender towers rise on a retail podium, on the roof of which a park is located. Raffles City, colloquially called the "horizontal skyscraper" because it is crowned by "The Crystal"—a 15,000 m^2 corridor, 300 m long, stretching over four towers [55]. It includes gardens, dining venues, exhibition spaces, a swimming pool and a hotel lobby. A public observatory provides visitors with a view of the confluence of the rivers through a glass viewing terrace. This is an idea that represents the expansion of public space in dense development, at the level of the "sky". Raffles City won the China Tall Building Innovation Award.



(**a**) (**b**) (**c**)

Figure 3. Level differences between streets, sidewalks and tracks in the Chinese city of Chongqing. (**a**) View from the bridge connecting the hospital roof with the adjacent building. (**b**) Lizba Station with the metro line crossing the residential building. (**c**) Hongya Cave Source: Anna Piętocha.



(**a**) (**b**) (**c**)

Figure 4. (**a**) Raffles City in Chongqing, 2024. (**b**) KingKey 100, 2025. (**c**) View from the bar on the top floor of KingKey 100, 2025. Source: Anna Piętocha.

3.3.4. Qianhai and KingKey 100 (Shenzhen)

Shenzhen is one of the cities with the fastest urbanization, which has quickly become a first-rank city in the world [56]. Qianhai is an area in Shenzhen, with an area of only 15 km^2, which gained its importance in the years 2010–2015. It is a strategically important region in the Pearl River Bay, bordering Hong Kong and Macau. It is, among other things, the location of the Shenzhen–Hong Kong Modern Services Cooperation Zone and is seen as a special zone within a special zone [57]. The megacity experienced significant urban expansion between 1979 and 2020 [58]. In a rapidly growing coastal city, balancing economic activity with ecological protection of the shoreline is a major challenge [59]. Qianhai is one of the most ambitious urban developments in contemporary China and is an example of mixed-use planning, in which work, living, recreation and transport are designed within one common space. Numerous public spaces were designed in the district, the main goal of which was to improve the quality of life and access to green areas within a radius of 200 m. Priority public transport is to be located within a radius of 200 m, restaurants and hotels—500 m, educational and health care services—1000 m. The city also uses so-called smart governance, in which technologies and innovations are used for public management. Sustainable Urban Public Transport (UPT) plays a key role in achieving Shenzhen's ambitious carbon reduction targets [60].

Sustainable development is visible in green infrastructure systems (green roofs, city parks or rain gardens). All buildings in Qianhai must meet international environmental standards and energy consumption in buildings is monitored and controlled. KingKey 100 located in Shenzhen, commonly known as KK100 (Figure 4b), was completed and put into use in 2011. It is located in the financial district and its 100-story tower is 441.8 m high. KK100 was designed by the architectural studio TFP Farrells and the construction company Arup. The complex includes five residential buildings and two commercial buildings. The tower has office and hotel space on 98 floors. The four highest floors house a garden and several restaurants. The structure is made of a steel frame and a concrete core without infill. Thanks to this solution, it is possible to achieve usable space along the entire façade and provide interesting views of the city (Figure 4c).

As in the case of the Shanghai Tower, lateral loading played a key role in the design of the structure. Lateral stiffness is supported by the use of giant diagonal struts [61]. A series of tests were performed for different building shapes in a wind tunnel to obtain the optimal corner shape [62]. The building is crowned by a roof consisting of a smooth, curved, glazed curtain wall and a steel structure. The building is LEED and Core and Shell certified at gold level. KingKey was built on a site that was previously occupied by dense but low-rise housing. Housing conditions were inadequate, so a Joint Development Initiative was established, with villagers as co-owners. To offset the costs of re-housing, the tower had to be exceptionally tall. The idea was also to preserve the social ties built over the years. The design was integrated with the city's transport network, which is particularly important for high-density projects. The tower acts as a "mini-city" that is intended to offer residents 24 h urban living that is better for the environment and interpersonal interactions.

3.3.5. Nanjing Vertical Forest Towers (Nanjing)

Vertical gardens are becoming one of the most popular green systems in the modern era. Buildings consume about 30% of the world's resources and about 40% of the world's energy, which has led to green buildings and facades being recognized as innovative solutions [63]. Measurements show that a layer of vegetation on facades can effectively reduce the temperature of the internal surface. This effect is more pronounced for facades with a higher density of foliage [64]. Such concepts have long been known in the history of urban planning as theories of garden cities. The development of vertical gardens began

when PatricBlanc presented a structure in the form of a wall covered with plants during the International Garden Festival in France, in Chaumont-sur-Lorie in 1994 [65]. Stefano Boeri—Italian architect is the author of the Bosco Verticale towers in Milan and the unfinished Nanjing Tower project in Nanjing. The Chinese concept consists of two towers resembling a vertical forest—significantly higher than its Italian predecessor. The taller building is to be 200 m high and will serve as an office and educational facility (floors 8–35) as well as a museum. The lower one, 108 m high, is to serve as a hotel. A common, twenty-meter podium with commercial, recreational and educational functions has been designed for both buildings. 600 tall and 200 medium trees in 27 local species are to be planted along the façade, as well as 2500 cascading plants and shrubs.

The project was created in 2018 and its aim is to contribute to the regeneration of local biodiversity. The assumption is to provide 18 tons of CO_2 absorption and produce 16.5 tons of oxygen per year [65]. The designed green facades are to contribute to improving air quality: they reduce pollution levels and capture dispersed solid particles, and natural photosynthesis helps to lower the ambient temperature. An additional benefit is reduced energy consumption by the cooling system.

3.3.6. CITIC Tower (Beijing)

Compared to other Chinese cities, Beijing's skyline doesn't have such a wide range of heights. This is due to two factors: the strict height limit in central Beijing, intended to protect views of the Forbidden City. The second is the region's high seismic activity. In 2010, a plan was initiated to build a Central Business District (CBD) comprising seventeen skyscrapers ranging in height from 50 to 500 m [66]. The Beijing CITIC Tower, also known as China Zun (Figure 5a, is located in the center of Beijing's business district (on plot Z15). Designed by Kohn Pedersen Fox Associates (KPF), the building opened in 2023. Construction began in 2018. The building stands 528 m tall and has 108 floors. It was the fastest construction of a 500 m-plus supertall building in China. The design concept combines traditional Chinese cultural and historical elements. The tower's shape is inspired by a traditional Chinese wine container called a "zun" used in religious ceremonies. The building's plan is a square with a rounded shape, gradually tapering from the bottom (78 m) to the center (54 m). The top gradually widens (to 69 m). The building's form is hyperbolic, and the structure meets demanding seismic and wind requirements.

China Zun is a multi-functional building. It comprises 60 floors of office space, 20 floors of luxury apartments, and 20 floors of a hotel. An observatory is located on the 108th floor, and a rooftop garden is located on the roof. The project is environmentally friendly and sets a benchmark for eco-friendly living and sustainable development in Beijing [28]. The building is LEED-CS Gold certified and has a China Certificate of Green Building Label—Three Star. CITIC Tower is connected to an extensive underground transportation network, including pedestrian crossings and four subway lines. In collaboration with a leading Japanese energy management company, CITIC Heye developed an integrated building energy management system (Z. BEMS) for CITIC Tower. This system focuses on fault diagnosis, energy consumption analysis, and energy savings verification through visual graphs. This system saved over 1.5 million yuan in operating costs in 2020. CITIC Tower also utilizes a free cooling system, which utilizes external cooling sources for air conditioning. A rooftop photovoltaic system generated a total of 941 kWh of energy in 2020. An energy feedback system was installed in the elevators, which allows a portion of the total energy consumption to be recycled directly to other equipment (reducing the elevator system's energy consumption by approximately 30%). Thanks to the use of BIM technology in the project, many collisions were avoided, the structural composition was

optimized, the precise positioning of materials was updated in real time, and material losses were reduced [67].



(**a**) (**b**) (**c**)

Figure 5. (**a**) View of Beijing CITIC Tower (center), 2024. (**b**) Guangzhou Chow Tai Fook Finance Center (right), Guangzhou, 2025. (**c**) Ping An Finance Center (tallest building), Shenzhen, 2025. Source: Anna Piętocha.

3.3.7. Guangzhou Chow Tai Fook Finance Center (Guangzhou)

Guangzhou is located deep in southern China, in the center of the Pearl River Delta Economic Zone. In terms of the scale and strength of its financial sector, it falls further behind the much more developed financial centers of Beijing, Shanghai, and Shenzhen [68]. The Guangzhou CTF Finance Center (Figure 5b) is a multi-functional skyscraper completed in 2016. It is the eighth-tallest building in the world, with 111 floors and a height of 530 m [69]. It is adjacent to the central park, an underground shopping arcade, and transportation hubs, making it very well integrated with the city and the entire region. The CTF comprises hotel, residential, and office functions, which are zoned. Above the office section is the residential section, then the hotel section, and finally the crown section. The offsets of the building allow for the creation of lush terraces and striking skylights. The building's façade is adorned with subtle terracotta glazing bars, which have played a significant role in the history of the East. This material is also environmentally beneficial, as its energy efficiency is significantly lower than that of aluminum, steel, or glass. Furthermore, it is corrosion-resistant and manufactured in multiple locations in China, significantly reducing the environmental impact of transportation. The building utilizes high-efficiency refrigeration units and heat recovery from these units. Photovoltaic panels are located on the roof. The building is LEED Gold certified for sustainable construction.

3.3.8. Ping An Finance Center, Shenzhen

The PAFC building (Figure 5c), completed in 2017, is located in the Furian Central Business District in Shenzhen. It is currently the fifth tallest building in the world and the second tallest in China. The architectural design was created by Kohn Pedersen Fox Associates. The building's foundation is an eleven-story podium with retail and conference space. It is the second-largest skyscraper in the world in terms of usable floor area (378,600 m^2). The skyscraper has 118 floors above ground and its floor plan is based on a square measuring 63 × 63 m. Contemporary high-rise buildings such as the Burj Khalifa

(828 m), the Shanghai Tower (632 m), and the Ping-An Finance Center (PAFC, 600 m) are characterized by increasing height, relatively low natural frequencies, and low damping coefficients, making them more sensitive to wind excitations than in the past. Therefore, the effect of wind has become a major problem in the design of wind-resistant structures [70]. The structural system consists of a composite concrete core, seven external double-layer chord trusses, four sets of steel outriggers, and eight super columns and diagonal braces [71]. The building is connected to neighboring properties and public transportation. The 116th floor features an observation deck called FreeSky, offering a 360-degree view. The building is equipped with 33 double-deck elevators. Sustainability consultant Arup developed a holistic strategy and integrated a range of high-performance technologies to achieve LEED Gold certification. The building features a high-performance glass façade that reduces heat gain while maximizing daylight access (reducing the need for artificial lighting). A solar analysis was conducted during the design phase to determine the building's orientation and glazing selection. External, vertical stone fins provide shading; their spacing and location were determined based on the results of a solar tracking analysis. As a result, the façade performs 20% better than required by local design regulations. This translates to lower cooling requirements and, consequently, energy consumption. Providing open space and setting the ground floor back increases wind penetration, thereby improving the surrounding environment.

3.4. Comparative Analysis

The examples discussed are four completed projects and one conceptual project. Three projects are located in China, one in Singapore (unrealized concept in China). Common features were noted, such as the idea of limiting the dispersion of the city by using vertical intensification of development. Table 1 contains a comparative analysis for the cited projects and the unrealized project.

Table 1. Comparative analysis of the examples discussed.

Name	Function	Characteristic Features	A Polemic with Shrinking Space	Pro-Ecological Solutions
Shanghai Tower	office, hotel, conference, gardens, observation deck	symbol of modern urban development -improvement of the city's image -strengthening the role of Shanghai -reference point for green buildings	-minimizes urban sprawl -intensifies development in the center of Pudong	-LEED Gold certification -China Green Building Three Star rating -double glazed -curtain walls -heat pumps -rainwater collection system
Marina One	office, residential, commercial, internal tropical garden	-a tropical garden as the heart of the layout -restaurants, shops, a fitness club, a swimming pool, a gym, a food court—supermarket as places for social interaction	-multifunctional intensification of the business center while maintaining green spaces	-LEED Platinum certificate -Green Mark -rich vegetation -organic shapes -interaction between building shapes and the garden facilitates ventilation
Raffles City	office, residential, hotel and service, garden, observation deck	-a 15,000 m^2 corridor stretching over four towers	-an idea illustrating the expansion of public space in dense development, at the level of the "sky"	-LEED certificate -roof garden reduces the urban heat island effect, increases biodiversity and absorbs excess rainwater, improves air quality

Table 1. *Cont.*

Name	Function	Characteristic Features	A Polemic with Shrinking Space	Pro-Ecological Solutions
KingKey100	office, hotel, restaurant, garden, observation deck	-mini city -it was built on the site of the former buildings (intended for people who previously lived in these areas)	-replaces horizontal urban functions with vertical structures, saving land	-LEED Gold certificate -China Green Building Label—Three Star
Nanjiing Vertical Forest Towers	office, educational space, museum, hotel, commercial space, recreational and educational	-vertical gardens	-adaptation of the green wall solution for a city with high urbanization pressure -contribution to the regeneration of local biodiversity	-production of 16.5 tons of oxygen per year -improvement of air quality, reduction of pollution level -photosynthesis helps to lower the ambient temperature.
Beijing CITIC Tower (China Zun)	Office, luxury apartments, hotel, observation deck, green roof garden	-The tower's shape is reminiscent of the traditional "zun" form -BIM technology was used in the design phase -it dominates the city	-Vertical structure -limiting urban sprawl	-LEED-CS Gold certified -China Green Building Label—Three Star -Integrated Energy Management System Z. BEMS -Photovoltaics
Guangzhou Chow Tai Fook Finance Center	hotel, residential and office	-Lush terraces and striking skylights -Terracotta glazing bar facade	-Division of the building into functional zones arranged one above the other.	-LEED Gold certified -Use of environmentally friendly materials -Refrigeration units -PV panels on the roof
Shenzhen Ping An Finance Center	office, observation deck, commercial complex	-stone ribs providing shading—less cooling required	-limiting urban sprawl -reducing the need for additional infrastructure outside the city center -promoting sustainable mobility	-LEED Gold certified -High-performance glass facade reduces heat gain and maximizes access to daylight

Source: Own elaboration.

4. Discussion

Rapid demographic and economic growth, and therefore urbanization, is one of the causes of environmental problems. Therefore, scientists and practitioners are trying to address this problem by incorporating environmental factors into urban development [72]. In a global context where sustainable development is a necessity, understanding carbon dioxide emissions in key regions is essential [73]. Global trends in urbanization and population growth are fundamentally changing the shape of cities. Vertical, increasingly compact forms are emerging in diverse locations [12]. A large number of tall and supertall buildings have been constructed in major cities such as Shanghai and Beijing, of which Shanghai is the most representative [74].

This is due to various factors, including economic, social, and geographic factors. The Chongqing metropolitan area struggles with limited space, being located in hilly areas and divided by rivers. China is characterized by a high level of internal migration and the associated demand for housing, which intensifies the pace of development. Shanghai, on the other hand, is an example of a megacity whose main city-building factor, in terms of high-rise buildings, is the creation of a prestigious business center. Pudong, the business center, contrasts with the low-rise, postcolonial buildings of the Bund. Another characteristic feature is the landscape created in recent years. Figure 6 illustrates the importance of Asian countries, particularly China, as leaders in constructing the world's tallest buildings. Ten of the world's twenty tallest buildings are located in China.

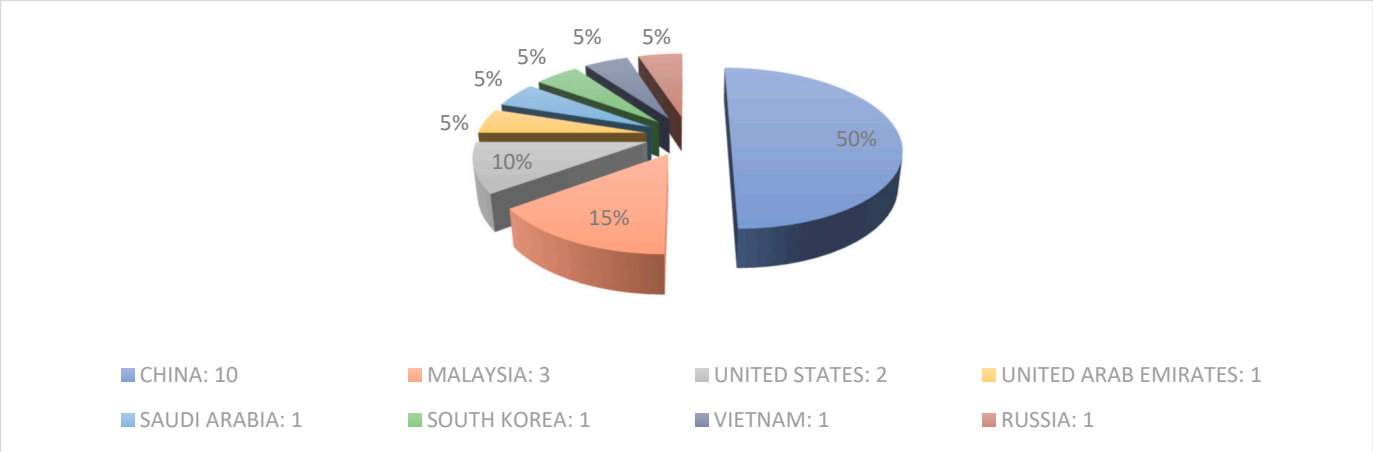


Figure 6. Division of the 20 tallest buildings in the world by country. Source: Own elaboration.

4.1. Green Building Certification

Carbon dioxide emissions from existing buildings significantly contribute to global climate change. This is related not only to energy consumption during building operation but also to material selection, waste management, water consumption, transportation, and more [75]. Various Green Building Rating Systems (GBRSs) exist, incorporating requirements for low carbon dioxide emissions [76]. Multi-criteria building certifications are becoming increasingly common. They confirm the use of environmentally friendly technologies and also influence the value and prestige of the building [77]. The novelty of this study is its inclusion of a Chinese perspective and local approach to multi-criteria building certification. Various green building standards have been developed in China, as well as technical standards for the operation and maintenance of green buildings [78]. In 2006, green buildings were officially introduced in China with the publication of the "Evaluation Standard of Green Buildings (First Version)." The ESGB is a technical document containing criteria and principles for evaluation, focusing on the use of measures to achieve energy efficiency. It takes into account seven assessment aspects: safety and durability; health and comfort; occupant convenience; material savings and material resource utilization; environmental livability; promotion and innovation [79]. The most important national multi-criteria building evaluation system in China is the Green Building Evaluation Label (China Three Star). This certificate is awarded on the basis of an ESGB assessment at least one year after the building has been put into use. Designed with China's climatic and urban conditions in mind, it also represents a local response to international standards such as LEED and BREEAM. The evaluation criteria include six categories: land, energy, water, resource/material efficiency, indoor environmental quality, and operational management. All of the discussed projects utilize advanced environmental strategies, such as LEED certification (appearing in all completed buildings). Many buildings are dual-certified, as evidenced by the discussed examples of the Shanghai Tower (Shanghai) and Kingkey 100 (Shenzhen), which achieved a three-star rating—the highest level of certification. This stems from the need to meet national requirements (China Tree Star) and the desire to award buildings international certification to attract international tenants (LEED). This study addresses the relatively under-reported aspect of dual certification in a regional–international setting. The Shanghai Tower exemplifies comprehensive certification and the implementation of advanced energy-saving and pro-ecological strategies. It takes advantage of the climatic conditions, including abundant rainfall, and is therefore equipped with rainwater-harvesting systems [80]. The prospects and potential for the development of ecological construction in China are extremely important.

4.2. Greenery

Vertical greenery is a key element of green architecture, encompassing the strategic placement of vegetation on facades, walls, and roofs. Benefits of its use include improved occupant health, increased property values, and enhanced aesthetics of urban spaces [81]. The results of the research by Zheng and Ying, conducted in the city of Shenzhen, indicate that the growth of urban vegetation leads to a reduction in the temperature in the city and also significantly improves thermal comfort [82]. The presence of greenery around and within buildings is an integral aspect of architectural space [83]. Nature-based solutions (NBSs) encompass a wide range of ecosystem-based strategies aimed at meeting the challenges of sustainable urban development. Vertical greening systems are defined as structures that allow vegetation to spread across the facade or interior wall of a building [15]. Greenery on high-rise buildings is a specialized application that integrates vertical vegetation systems with high-rise architecture. The goal is to increase carbon sequestration, mitigate the urban heat island effect, and improve air quality. The vertical dimension of cities offers a proposal for addressing climate change in densely populated urban environments [84]. In each example, greenery plays a significant role—in the form of vertical gardens on facades and parks that enhance biodiversity and climate. It also contributes to reducing air pollution and the urban heat island effect. Green infrastructure, therefore, serves more than just an aesthetic purpose—it is an integral element of climate change adaptation and mitigation strategies. Combined with passive architectural solutions (e.g., natural ventilation and solar control), it significantly reduces the energy consumption needed for cooling and heating buildings. Marina One in Singapore, with its lush, green heart—a central garden—provides an urban oasis amidst the skyscrapers. The design reflects a deep understanding of Singapore's tropical climate and a commitment to improving urban living through thoughtful architectural interventions [85]. Sky gardens are open, green spaces located above ground level, on floors, and rooftops, blending seamlessly with tall buildings in densely populated cities. They provide alternative public spaces by integrating vertical space [48]. Another such example was described in the Raffles City case study, where designers incorporated public spaces with greenery and services onto the roofs of buildings. Sky gardens have the potential to support urban sustainability in environmental, economic, and social terms. They contribute to both climate change and offer a new type of semi-public space in cities with high population density and land prices [86]. Sky gardens further integrate residents by creating recreational spaces for them.

4.3. Multifunctionality

The development of contemporary urban centers is based on the assumption that buildings are increasingly complex structures, both in terms of size and purpose. Consequently, they are referred to as multifunctional buildings. This aims to optimize built spaces. From the conceptual phase through operation to disposal, multifunctional spaces should ensure aesthetics, functionality, efficiency, and safety, as well as environmental protection [87]. The ground floors of buildings often serve as a showcase and generate traffic in the area. Currently, they most often serve as restaurants and retail spaces [88]. Based on Table 1, it can be concluded that each building serves multiple functions, with an office function appearing in each position. Public and social functions, such as squares, galleries, viewpoints, and the terrace in Raffles City, increase the accessibility of buildings and contribute to their integration with the surrounding environment. Furthermore, they allow residents and tourists to experience the high-rise space. Mixed land use promotes economics and efficiency, which can help alleviate urban problems and promote sustainable development [89]. Raffles City is a response to the shortage of land in the mountain city

and presents a vertical way of shaping the functions, but at the same time it is criticized for being designed at the lowest point of the city, blocking the view of Chongqing [53].

4.4. Accessibility

Excellent accessibility is a key condition for sustainable development, as it reduces emissions from individual transport. Transit-oriented development (TOD) involves the creation of pedestrian and walking routes centered around high-quality rail systems, which in turn allows for car-free mobility and reduces the stress associated with commuting. This trend also contributes to combating the global problem of climate change, reduces air pollution and greenhouse gases, and is also related to energy security, as by creating a dense network of pedestrian routes, it reduces the need to drive and therefore energy consumption [90]. Multifunctionality combined with mobility favors the development of 15 min cities, where basic needs such as services, healthcare, education, work, and recreation are met in the immediate vicinity. All are within a 15 min walk or bike ride from the house [91,92]. Both Marina One, Raffles City, CITIC Tower and Guangzhou CTF Finance Center are served by well-functioning public transport (in Chongqing, the metro station is right in front of the entrance square).

4.5. Landmark and Observation Decks

Architectural heritage and its symbolism play a key role in defining urban landscapes. As distinctive landmarks, they help people orient themselves in unfamiliar surroundings. Six types of landmarks are distinguished: historical, urban (square), skyscraper, everyday urban zones, personal perception, and circulation patterns. People choose elements that suit their orientation. These landmarks can be naturally produced or man-made—thus, they constitute a type of sign and symbol for communication tools [93]. In addition to their navigational role, landmarks strengthen urban identity [94]. The projects discussed are iconic—they constitute a landmark of a given city, not only due to their above-average height and shape, but also due to their unique location. This character is often used for marketing purposes (as advertising for the city) and urban planning (as a landmark). Projects from China have observation decks accessible to all users (in some cases for a fee, e.g., the Shanghai Tower observation deck).

4.6. Threats and Limitations

4.6.1. Compact City vs. Vertical City

Research on the compact city has evolved with the growing awareness of inevitable climate change. The dominant debates are primarily related to traditional Western forms. Simon Elias Bibri's study indicates that compactness, density, diversity, sustainable transport, land mixing and green spaces are the basic design strategies for planning and developing compact cities [95]. Vertical urbanism offers an alternative to the compact city, recognizing the influence of global cultural contexts on shaping varying urban density. This issue represents a research gap, and the rapidly developing new urban fabric of Chinese cities serves as a laboratory of sorts [27]. Cities around the world are unprepared for the integration of tall buildings because they can exacerbate multidimensional problems and lead to vertical sprawl, with far worse consequences than horizontal sprawl. Jan Gehl, in his books 'Life Between Buildings' [96] and 'Cities for People' [97], criticized tall cities and praised low-rise ones. In past, Hans Blumenfeld, in his book 'The Modern Metropolis' [98], condemned tall cities for destroying historical fabric. Jane Jacobs glorified pedestrian-friendly spaces [99].

4.6.2. Social Isolation and Human Scale

Urban design is a crucial element that influences the quality of life and plays a significant role in making cities livable spaces [100]. One of the key issues in 20th-century

urban planning discourses was the human scale, which provided urban planners, architects, sociologists, and housing reformers with an important epistemological framework. It helped define the social in technical terms. In practice, this measure influenced plans for decentralization and delimitation of the urban fabric. Planners sought to adapt urban agglomerations to what they perceived as measurable on a human scale. They collected anthropometric data, which served as criteria for defining the built environment [101]. Due to their height, high—rise buildings inherently violate human scale.

A vertical layout can promote social isolation and also create a difficult space for children, who may feel like they are in a closed space, deprived of the opportunity to explore. Apartments are often presented as living spaces for singles and young couples [102]. However, Lia Karsten's research indicates that living in vertical apartments and a happy family life are not necessarily contradictory [103]. Based on a literature review, the researcher identified problems associated with vertical family life. The main problem was raising children, who needed to be cared for and provided with an appropriate environment in which to live and play. Lifestyle diversity influences the choice of where to live. Research by Taro Hirai in Tokyo indicates that demographic aging in high-rise buildings is faster than in other residential buildings, as the age groups of residents are concentrated in the generations born between 1946 and 1955 and 1966 and 1975 [104].

4.6.3. Economics

Tall buildings are associated with higher financial costs because they require advanced structural, mechanical, and electrical systems. Their construction can also generate significant amounts of carbon dioxide. High-rise buildings also affect wind patterns, hindering natural ventilation and altering the cityscape. Structures require more materials due to the higher bending moments caused by high-speed wind forces at the top of the building [105]. The results of the study by Lopez-Ordoñez, C., indicate that an increase in vertical building density leads to a decrease in the surface-to-volume ratio and, therefore, results in a decrease in the cooling demand [106].

4.7. Key Challenges and Future Directions

Modern cities are faced with numerous, difficult problems, and urban planners must use various fields of knowledge to solve them [107]. A key element of urban design is balancing multiple goals to create environments that are optimized for people's health and well-being [12]. Promoting sustainable development and maintaining urban vitality are key issues of global importance in the context of accelerating globalization [108]. Figure 7 presents the main issues and key elements of sustainable design, divided into three criteria: people, the environment and high-rise buildings.

Designing dense, high-rise buildings is primarily related to technical, structural, economic, and environmental issues. However, complex social processes are clearly evident. There are neighborhood initiatives that may oppose development, as well as public and private stakeholders facilitating the creation of a new, dense, vertical city form [109]. The design of high-rise buildings is also related to a new model of high-rise building management, including compliance with strict regulations [110], including monitoring the condition of structures in high-rise multi-story buildings [111]. Mitigation and adaptation measures must be designed strategically by designers, urban planners and decision-makers to reduce the risk of urban heat island (UHI) [112].

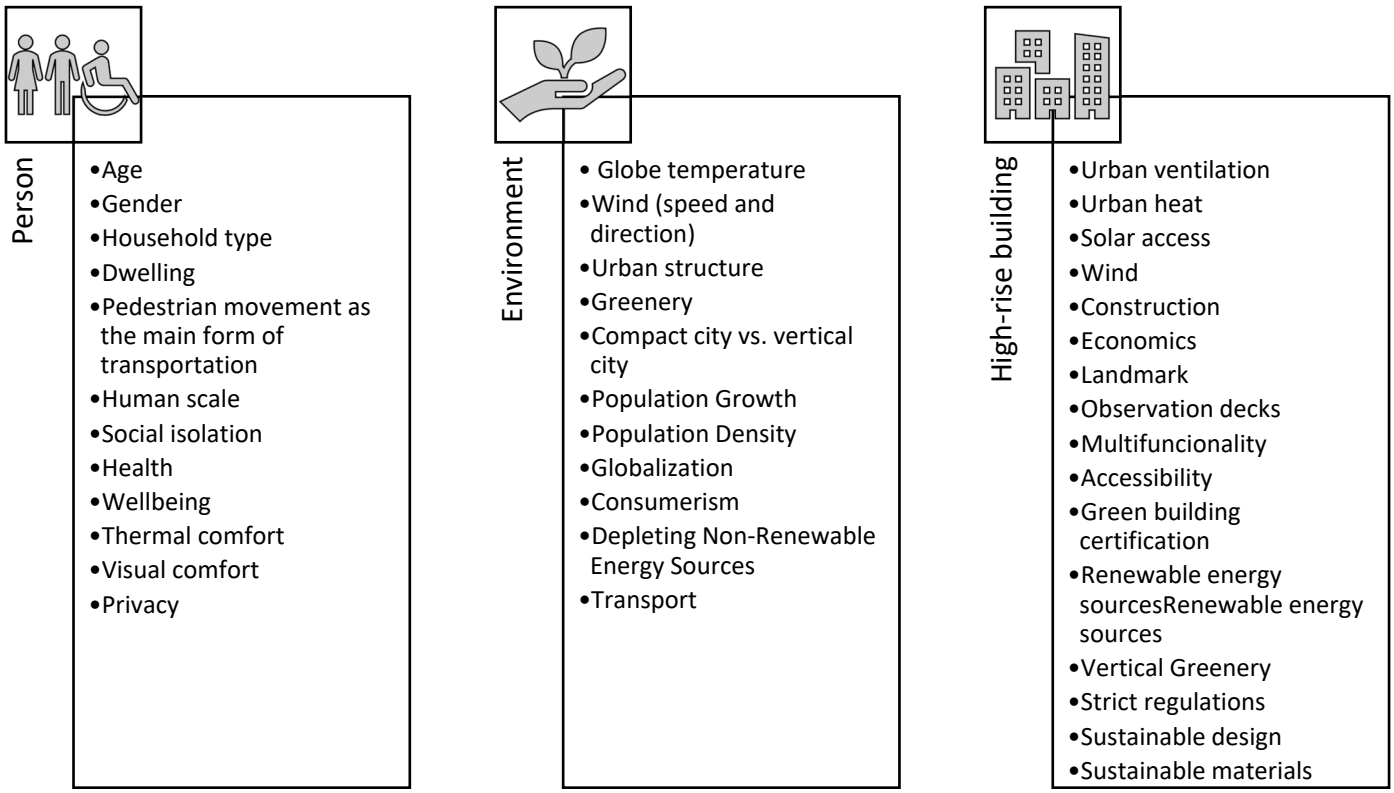


Figure 7. Key elements related to sustainable design, divided into three criteria: people, the environment and the tall building. Source: Own elaboration.

5. Conclusions

This study highlights the growing role of vertical architecture and vertical cities as strategic responses to shrinking urban space and increasing population density. Modern skyscrapers are designed to use wind energy, reduce lateral loads or balance solar gain while providing natural ventilation. The contribution that this type of development makes to the dialogue on sustainable urban development is important. It has been noted that contemporary high-rise buildings are designed as separate elements, without any relationship with other such buildings. They often become elements of identity or, like the Shanghai Tower, a symbol of modernity and urban development. The examples cited represent advanced ecological strategies and greenery is treated as one of the very important design elements. In addition to its aesthetic role, it also serves as an air purifier or a factor supporting the maintenance of a comfortable temperature inside the building (which is related to energy demand). An interesting phenomenon is the role of social spaces in high-rise buildings and the relationship between the place of residence and the common space. The example of Raffles City in Chongqing represents an innovative approach to designing public space, which is a corridor designed at a huge height—on the roofs of 250 m buildings. All examples are characterized by the fact that they perform many functions, including office, residential, hotel, recreational, commercial and educational, which supports sustainable development, because it contributes to reducing the number of commutes and thus affects the reduction of greenhouse gas emissions. Multifunctionality applied vertically becomes a response to the increase in spatial needs resulting from population growth. The research highlights the potential of vertical cities to redefine future urban development in the context of energy transition and climate resilience.

5.1. Theoretical and Design Conclusions

Rapid demographic, economic, and urban development significantly contribute to environmental challenges. Consequently, researchers and practitioners are striving to address these issues by integrating environmental considerations into urban development. Understanding carbon emissions in key regions of the world is essential for the broader context of sustainable development. Urbanization and population growth are fundamentally transforming urban landscapes, with vertical and increasingly compact forms emerging in various locations. Asian countries, particularly China, are leading the way in building some of the world's tallest buildings, as exemplified by cities like Shanghai and Beijing. Research to date indicates that there is a need for further research on verticality that goes beyond individual buildings and for deeper reflection on the planning challenges of the 21st century in cities with high buildings. Urban planners play a key role in the planning and development of vertical estates, on whom depends the management and diversification of the impact of development on the environment.

The need for interdisciplinary activities is clear. Green building certifications play a key role in mitigating the effects of climate change, taking into account not only energy consumption during building operation but also materials, waste management, water consumption, and transportation. The introduction of vertical greenery systems and sky gardens helps improve biodiversity, air quality, and thermal comfort. Multifunctionality is gaining importance in contemporary urban centers, optimizing built space by combining office, retail, and public functions. This approach supports economic efficiency and social integration, contributing to sustainable urban development. Tall Buildings (TBs), Transit-Oriented Development (TOD), and Sustainable Urban Transport (UPT) represent a crucial sustainable development option for future cities. Figure 8 contains Implications for further research and Guidelines and constraints for the design of sustainable vertical cities. Challenges associated with vertical cities include adapting space to the human scale, design complexity, construction, construction and material costs, and the environmental impact associated with building materials and the urban microclimate.

5.2. Research Perspectives

This analysis highlights the urgent need to develop new research areas related to the sustainable design of vertical cities. The rapid economic growth, escalating energy consumption, and depletion of natural resources leading to climate change present significant challenges for urban planners and architects tasked with designing a new type of sustainable city. This research highlights the emerging role of vertical architecture and vertical cities as strategic responses to shrinking urban space and increasing population density. Future studies should further explore the multifunctionality of vertical urban environments and their ecological benefits, with particular focus on how advanced pro-ecological strategies—such as integrated greenery and temperature regulation—can be optimized in diverse climatic and cultural contexts.

Moreover, there is a notable research gap in our understanding of vertical development beyond isolated skyscrapers, encompassing entire urban structures and systems, as exemplified by cities like Chongqing. Expanding multidisciplinary approaches, including empirical case studies and theoretical modeling, can provide deeper insights into the complex interactions within vertical cities. This will aid in formulating practical guidelines for creating dense yet sustainable and environmentally friendly urban habitats.

Interdisciplinary

- Urban planners, architects, engineers, environmental scientists, sociologists, economists, and policymakers must collaborate to integrate technical, environmental, and social dimensions.
- Interdisciplinary cooperation ensures that solutions are not only structurally and technologically feasible but also socially inclusive, culturally appropriate, and ecologically responsible.

Multifuncionality

- A defining characteristic of sustainable vertical cities is multifunctionality—the integration of diverse functions such as residential, commercial, recreational, and public spaces within a single structure or complex.
- This approach maximizes land use efficiency, reduces the need for long commutes, and fosters vibrant, 24-hour urban environments.

Understanding carbon emissions

- In vertical cities, emissions arise not only from operational energy use but also from construction processes, embodied carbon in materials, and transportation systems.
- Quantifying emissions at all life-cycle stages enables targeted mitigation strategies.
- Integrating carbon assessment tools early in the design process can guide decisions on energy systems, materials, and building orientation, ultimately reducing the carbon footprint.

Renewable energy sources

- Incorporating renewable energy sources—such as solar, wind, and geothermal—into vertical cities reduces dependency on fossil fuels and supports long-term sustainability goals.
- High-rise structures present opportunities for energy generation through building-integrated photovoltaics, wind turbines, and energy recovery systems.
- The challenge lies in adapting renewable technologies to dense urban contexts, where shading, wind patterns, and limited surface area can impact efficiency. Innovative solutions, such as façade-integrated solar panels and shared district energy systems, can help overcome these constraints.

Green building certifications

- These certifications encourage advanced ecological strategies, from rainwater harvesting to waste reduction.
- Achieving and maintaining certification requires rigorous documentation and ongoing performance monitoring,

Transit Oriented Development (TOD), and Sustainable Urban Transport (UPT)

- In vertical cities, dense development should be seamlessly connected to high-capacity, reliable public transport networks, supported by pedestrian-friendly streets and cycling infrastructure.
- The goal is to create “15-minute cities,” where essential services are accessible without long commutes.
- Challenges include integrating transit hubs into high-density developments without causing congestion and ensuring equitable access to mobility options.

Sustainable design and sustainable materials

- Locally sourced, recycled, and renewable materials reduce environmental impact while fostering regional economies.
- natural ventilation, daylight optimization, and thermal mass utilization are critical for reducing operational energy demand.

Thinking about the vertical city as a whole, not just individual high-rise buildings

- Sustainable vertical urbanism requires a systemic perspective that extends beyond individual skyscrapers to the functioning of the city as an interconnected whole.
- Exploring the integration of vertical cities into broader urban planning frameworks

Thinking about challenges and threats

- Vertical cities face unique risks, including social isolation, loss of human scale, high construction and maintenance costs, and potential environmental side effects such as urban heat islands and wind tunnel effects.
- Challenges include balancing privacy with public accessibility

Figure 8. Implications for further research. Guidelines and constraints for the design of sustainable vertical cities. Source: Own elaboration.

Future investigations could also address socio-economic implications, governance frameworks, and technological innovations that support vertical urbanism. Such research will be essential for urban planners and policymakers aiming to balance urban density with sustainability goals and improve quality of life in rapidly growing metropolitan regions. A very important task for future researchers is exploring the integration of vertical cities into broader urban planning frameworks and addressing the challenges of high-density urbanization.

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Abbreviations

The following abbreviations are used in this manuscript:

LEED	Leadership in Energy and Environmental Design
UHI	Urban heat Island
KK100	KingKey 100
GBRS	Green Building Rating Systems
NBS	Nature-based solutions
TOD	Transit-oriented development

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