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Key Trends in Supertall Buildings - A Review of the World's 100 Tallest Buildings in the Last 30 Years

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Abstract The last 30 years have seen a rapid growth in the number of supertall buildings across the world, with newly completed buildings continuing to rank among the tallest 100 every year. Chinese projects notably play a pivotal role in these constant updates. It is caused by the interweaving of population and urbanization, economic considerations, and further, a series of accompanying urban problems. This paper focuses on the world's 100 tallest buildings in the last 30 years, and compares this collection of projects across five years via the dimensions of height, distribution, function and structural material. The intention is to discuss and interpret the influence factors and developing trends, some of which have been apparent over a dozen years, while others are just beginning to take shape, thus to provide an opportunity to preview the types of supertall buildings in the future.

Keywords Distribution, Function, Structural Material, Supertalls, Trends

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1. Introduction

With the development of high-density cities, the number and height of tall buildings globally have been rising in the past 30 years. Every year, there are newly completed buildings ranking among the 100 tallest buildings in the world. The number, function and structural material of supertall buildings in various regions have shown different patterns, especially since the beginning of this century. This paper selects the 100 tallest buildings of the past 30 years and observes milestones every five years for comparison and analysis. Please note that there were 102 buildings entering the 100 tallest list in 2002 and 101 in 2022.

In recent years, demand has increased for increased quality in tall building development, such as green and sustainable features, people-oriented, usable space, and integration with the urban environment. The emergence of some special circumstances, such as the epidemic situation and China's height-limiting regulations, will also have an impact on the future of supertall buildings.

2. 100 Tallest Buildings Worldwide

Overall, the height of the world's tallest building and the average height of the 100 tallest buildings have been increasing through the past 30 years. During the reviewed period, Willis Tower in Chicago became the highest in the world since it was built in 1974, with a height of 442.1 meters, and remained so until it was replaced by the Petronas Twin Towers in Kuala Lumpur, Malaysia, after they were introduced in 1998.

The TAIPEI 101, 508 meters high, replaced the twin towers six years later. And another six years later, in 2010, Burj Khalifa in Dubai was completed; at 828 meters high, it is nearly double the height of Willis Tower. It is expected to remain the world's tallest building over the next few years. Though it began construction several years ago, as of this writing it is still unknown when the Jeddah Tower in Saudi Arabia, planned to exceed 1,000 meters' height, will complete.

Though less dramatic than the steep rise in the height of the world's tallest building, the "shortest" height of the tallest 100 buildings in the past 30 years has shown steady growth at a rate of greater than 50 percent. Within the reviewed period, 2015 was the first year to witness all of the tallest 100 exceed supertall height (300 meters).

The average height of the 100 buildings also grew steadily, in line with that of the "shortest" buildings. It seems that the increase in average height is not strongly correlated to the height of the by the tallest building in a given year. For example, in the five years from 2007 to 2012, the gap between the two highest buildings was the largest, with an increase of 320 meters, but the 100-

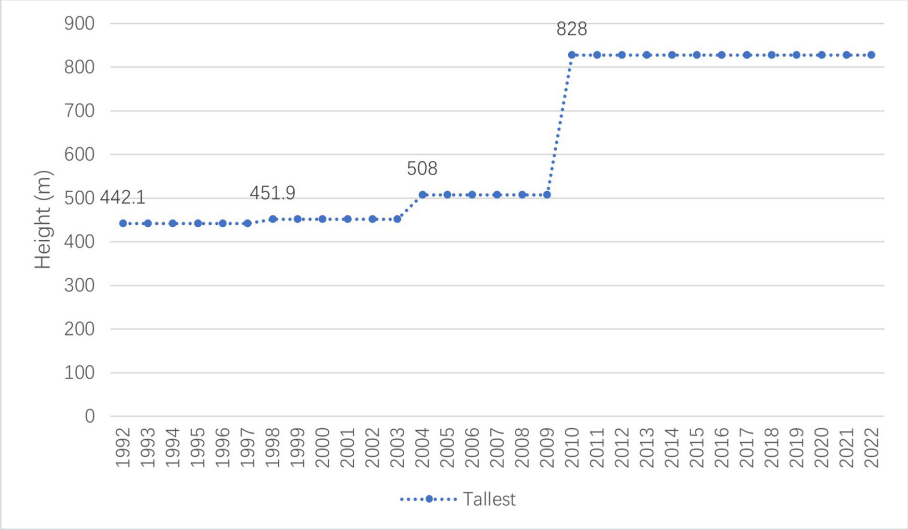


Figure 1. The height of the tallest building, 1992 to 2022, with new height records indicated.

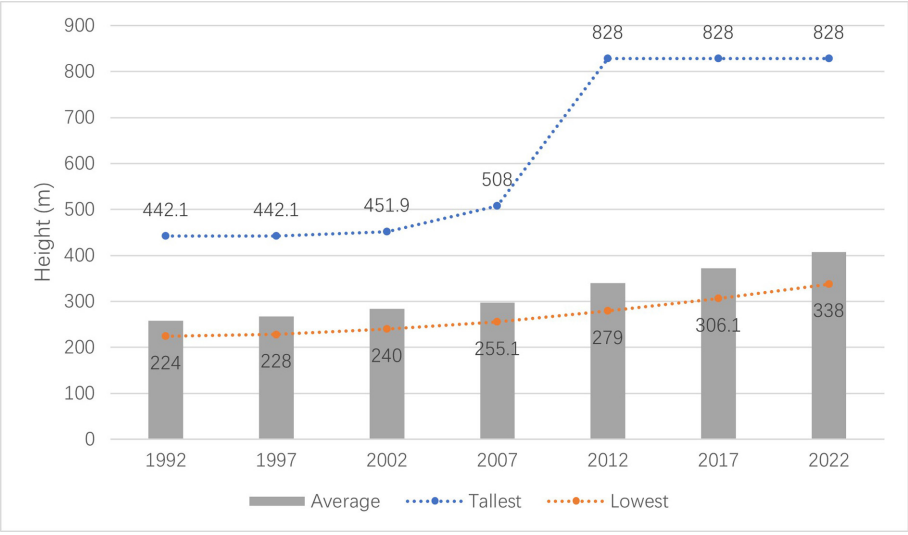


Figure 2. The average height of the 100 tallest buildings in the world, showing trendlines of the tallest and shortest buildings in the dataset.

building height average did not change significantly. This demonstrates that the height of most of the tallest 100 buildings are close to the average height, but significantly few are close to the height of the tallest building. In view of the steady growth of average height and minimum height in the past 30 years, it is reasonable to believe that the growth rate will not change significantly in the next 10 to 20 years.

Until 2010, the average height exceeded half of the tallest building's height at in any given year. After the appearance of Burj Khalifa, the average height has continued to increase, but has been significantly lower by comparison. For example, in 2022, the average height was 407.3 meters, less than half the height of the Burj Khalifa. The average height and the height of the "shortest" building will increase every year, but the height gap with Burj Khalifa is still considerable.

2.1. Distribution

Figure 3. The geographic distribution of the world's 100 tallest buildings from 1992 to 2022.

The absolute share of the North American market in the last century has been accompanied by a continuous decline from 74 to 14 percent in the past 30 years. In contrast, China's share has increased year by year, from 2 to 53, with the number exceeding that of North America during the period from 2007 to 2012. The total number of Asian countries with buildings in the tallest 100, except China, has not fluctuated greatly in the past 30 years, accounting for 10 to 20 percent of the total. The peak

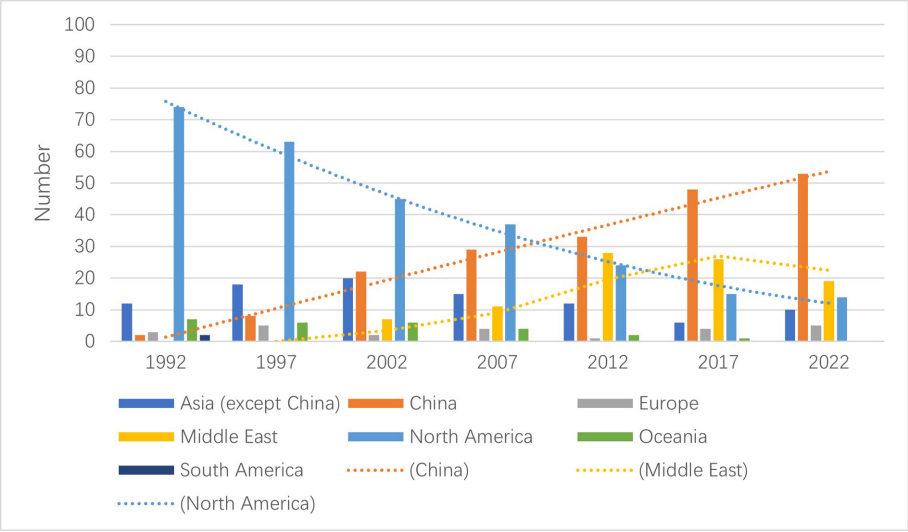


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appeared at the beginning of this century, around 2002, and also at the same time, it was exceeded by China.

In addition, it is worth noting that the Middle East, though it had no building entering the tallest 100 until the beginning of this century, subsequently grew its number rapidly. About 10 years later, in 2012, the proportion of buildings in Middle East was relatively balanced against that in North America and China, at about 30 percent. Since then, it has declined, but has still slightly exceeded that of North America.

The distribution of the tallest 100 was mainly in North America in the last century. After entering this century, it gradually moved to China and Middle East, with the largest number in China in the last 10 years. In view of the large proportion of Chinese projects in the tallest 100, the height-limit guiding principle introduced by China in 2021 (no new buildings of more than 500 meters and strict restrictions on new buildings of more than 250 meters) may affect the growth of the average height of the tallest 100 in the future and slow it down. And the proportion of China in the global geographical distribution will decline, though these effects will not be obvious in the short term.

2.2. Function

Figure 4. The function of the world's 100 tallest buildings, 1992 to 2022. A mixed-use tall building contains two or more functions, where each of the functions occupies a significant proportion of the tower's total space.

In terms of function, it is obvious that office and

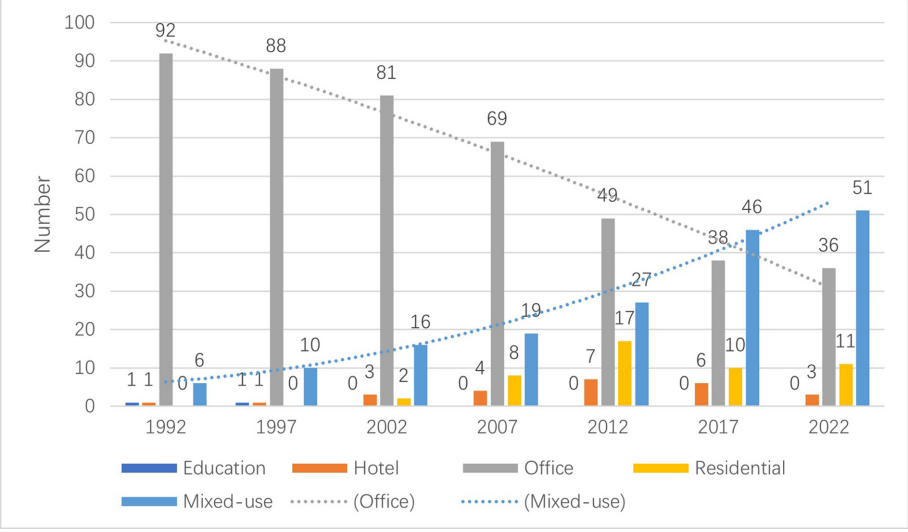


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mixed-use have been the absolute main force of the world's top 100 buildings in recent years. The difference is that the proportions of these two types have been inverted. The number of office-only buildings is decreasing year by year, from 92 in 1992 to 36 in 2022. In contrast, mixed-use has grown from 6 to 51, exceeding the proportion of office-only buildings. This transcendence took place in the 2012-2017 period, achieving closest parity in 2015 (40 office and 42 mixed-use buildings). It is reasonable to believe that the proportion of mixed-use will further increase in the future, and correspondingly, the office-only function will continue to decrease.

The number of buildings in the 100 tallest list with education and hotel functions have always been relatively small. It is noteworthy that residential has only entered the tallest 100 since the onset of the 21st century, but the number increased significantly, to 17 in 2012. Although it declined later, it still in the double digits. However, it is not likely to occupy a large share like office or mixed-use in the long run, based on the overall situation of the past 30 years.

There is a clear correlation between the function of supertall buildings and the operating benefits. With the development of the economy and the practicalities of operation, the market is increasingly aware that, compared with a single-function program, the distribution of multiple functions, and consequently floor layouts, across the height of a building is undoubtedly less risky and more flexible for the long-term operation of a supertall building. On the other hand, as residential and hotel are living spaces, which require less population density and supporting services, this is more suitable for the upper tiers of tall buildings, which tend to be narrower. At the same time, the characteristics of living spaces can make the typical floor relatively small, which is also suitable for the design of supertall buildings with reduced upper area for the consideration of structure and mechanics. All these make the mixed-use distribution of the office function to the lower tiers, and residential or hotel to the upper tiers, a popular configuration. There are also changes that cannot be ignored after the outbreak of COVID-19. Along with the development of Internet technology, there has been a direct change in the urban lifestyle: a blurring of the boundaries between work and spare time. Remote offices and shared spaces are more in demand, demand for fixed office space is reduced; this suggests mixed-use will increase its market share in terms of the proportion claimed within the future world's 100 tallest buildings.

2.3. Structural Material

Figure 5. The structural material of the world's 100 tallest buildings, 1992-2022. Composite: A combination of two or more materials (e.g., steel, concrete, timber) are used together in the main structural elements. Mixed: Utilizes distinct systems (e.g., all-steel, all-concrete, all-timber), one on top of the other.

In terms of structural material, the three most commonly used are concrete, steel and composite, although they have undergone completely different changes. The use of steel is decreasing significantly, representing 50 buildings in 1992 to only seven in 2022. On the contrary, the number of composite buildings has become the favored choice, growing from 28 buildings in 1992 to 62 in 2022. Interestingly, the number of buildings constructed of concrete has both grown and declined over the past 30 years, but it always accounts for between 20 and 40 percent of the total. In the 2002 to 2007 period, the proportion of these three materials reached a relatively

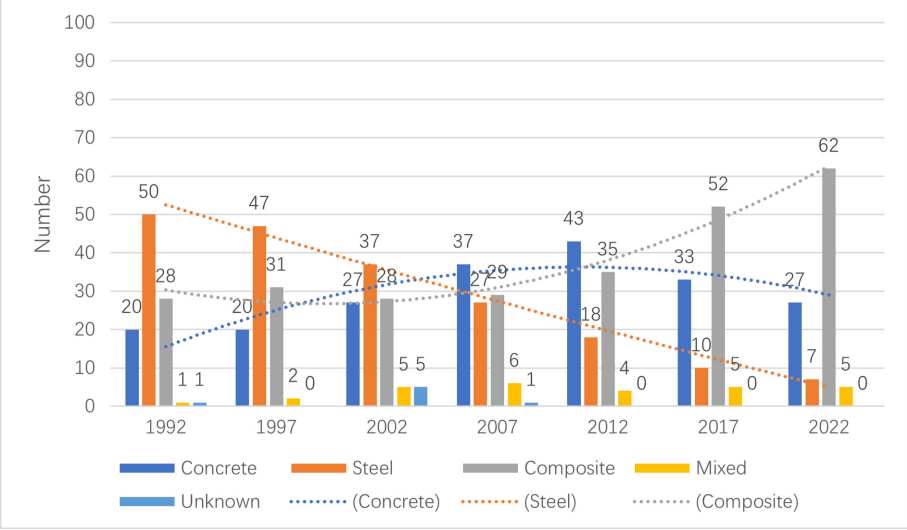


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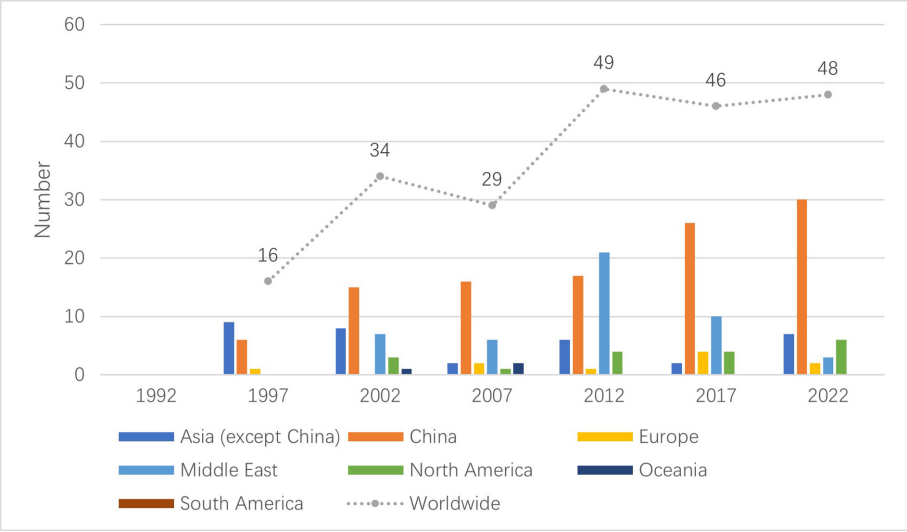


Figure 6. The distribution of buildings entering the world's 100 tallest buildings list. The dotted trendline indicates the number of buildings replaced in the list of the world's 100 tallest buildings every five years.

balanced level, around 30 percent. Since then, trends have markedly changed.

Traditionally, steel had been the most common for the construction of tall buildings. However, considering material, construction cost and technical requirements, steel and concrete each have their own advantages and are more efficient in comprehensive use. Taking function into consideration, steel may be more suitable to office construction, and concrete is more appropriate for residential and hotel functions. Therefore, with the increase of mixed-use functions made up of office and residential or hotel, the use of composite structural material is increasing also.

3. Buildings Entering the Tallest 100 Every Five Years

Compared with five years ago, the buildings entering the tallest 100 have changed a lot, especially since 2000. From 2007 on, the replacement rate of the tallest 100 is close to 50 percent every five years. Of the tallest 101 buildings in 2022, only six buildings were built in 1992 and earlier; that is, the only six of the world's 100 buildings in 1992 remain on the list in 2022. Of these, four are located in the United States and two are in China. In other words, in the past 30 years, 95 buildings with a height of 338 meters or greater have been completed globally. Historically, as of 1992, only six of those buildings

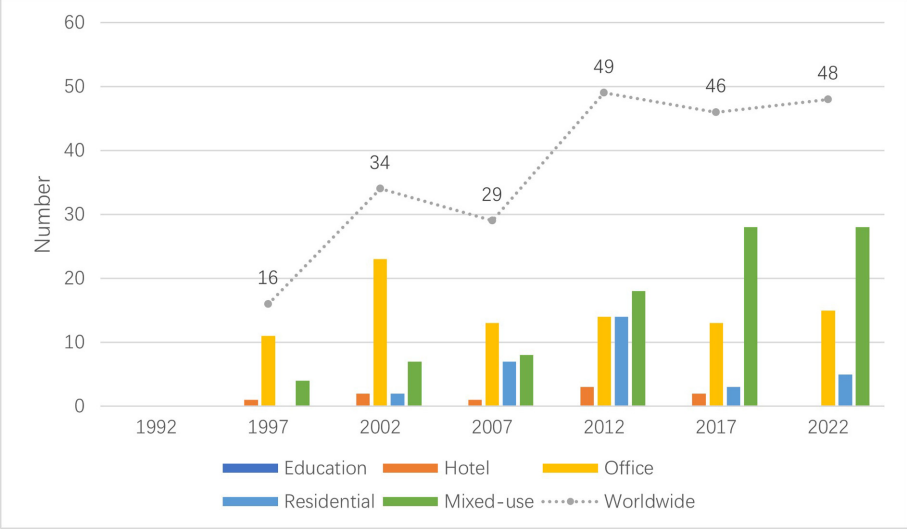


Figure 7. The functions of buildings entering the world's tallest 100 buildings. The dotted trendline indicates the number of buildings replaced in the list of the world's 100 tallest buildings every five years.

had reached a height of 338 meters or more. In fact, by 1992, there were a total 13 supertall (300-meter) buildings in the world; the number was 221 in 2022.

Figure 6. The distribution of buildings entering the world's 100 tallest buildings list. The dotted trendline indicates the number of buildings replaced in the list of the world's 100 tallest buildings every five years.

From the perspective of geographical distribution, China has the largest number of buildings entering tallest 100 in most periods, and the number has been growing continuously. By 2022, thirty of the 48 new tallest 100 were located in China. Most notable is the incremental distribution in the five years from 2007 to 2012. The Middle East had 21 replacements in the list, exceeding the 17 in China. Only China and the Middle East have double-digit replacement rates in the incremental process.

Regarding function, increments are still dominated by office and mixed-use. Except for a large increase in 2002 (to 23 percent), the proportion of office function in other periods was stable, ranging from 11 to 15 percent. The total number of buildings entering the tallest 100 before 2007 was mainly affected by the proportion of office function, while the sharp increase after 2007 was due mainly to the continuous growth of mixed-use; the increment of office during this period was stable. It is notable that there were 49 in 2012, the largest replacement volume seen in five years. And the numbers were close in the residential, office and mixed-use categories, which was not found in other periods, considering the small increase of residential in most periods.

In terms of structural material, the incremental proportion of concrete is basically in a symmetrical state, having reached a peak of 28 percent in 2012 and gradually decreasing since then. It is now surpassed by the continuous increase of composite as the preferred means of supertall building construction. In 2022, composite construction accounted for 37 of the 48 buildings entering the 100 Tallest list, accounting for 77 percent of the total. According to current development trends, this proportion will be higher in the coming years.

From 2007 to 2017, there was a relative balance in the proportions among the evaluated characteristics, transitioning to transcendent trends afterwards. In terms of the geographical distribution of the 100 tallest buildings, from 2007 to 2012 the proportion of North America, China and Middle East reached equilibrium, and the numbers in China began to exceed those of North America. In terms of function, from 2012 to 2017, the number of mixed-use buildings began to exceed that of office. For structural material, between 2007 and 2012, steel, concrete and composite reached equilibrium, and the number of composite buildings began to exceed that of steel. As far as buildings entering the tallest 100, measured every five years, it was around 2012 that about half of the replacement volume was reached. Regarding function, it was also around 2012 that the proportion of office, residential and mixed-use reached an equilibrium. With structural material, the prevalence of composite construction exceeded that of concrete in the 2012-2017 period.

4. Features and Trends of the Tallest 101 Buildings in 2022

Most of the projects in the world's 101 tallest list in 2022 have been completed in the past 15 years, accounting for 85 percent of the total. In terms of the potential features and commonalities of the tallest 101, it is obvious that the observatory is the most prevalent feature. It appears in 34 projects in all of the five-year periods since 1992, with the greatest number accumulating in the past five years. The observatory floor is a unique space in tall buildings for sightseeing. Compared with ordinary

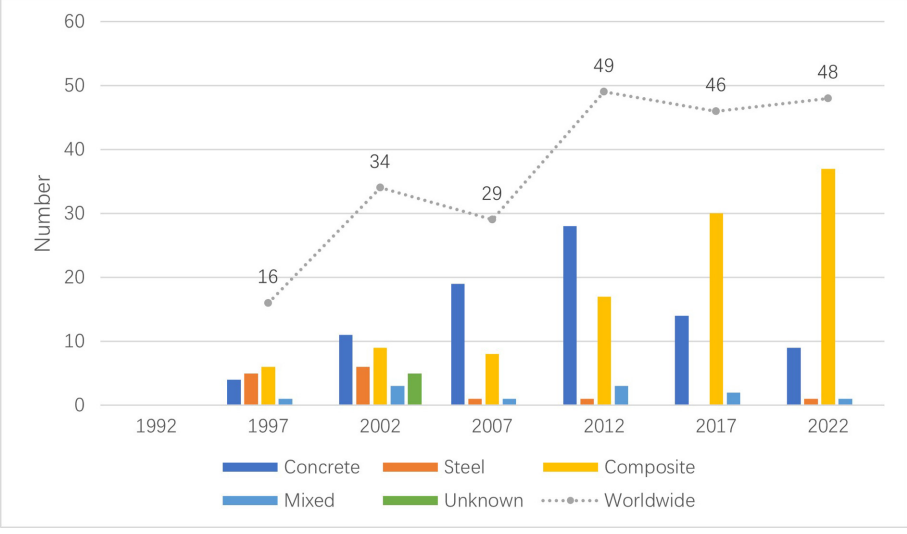


Figure 8. The structural materials of buildings entering the list of the world's 100 tallest buildings.

Table 1. Enumeration of the features of the tallest 101 buildings in 2022, grouped into five-year construction periods since 1992

Construction Period	To 1992	1993-1997	1998-2002	2003-2007	2008-2012	2013-2017	2018-2022	Total
Total number	6	3	5	2	17	20	48	101
No. buildings with an observatory	4	1	3	1	8	6	21	34
No. buildings with a Skybridge	0	0	2	0	0	0	3	5
No. buildings in transit-oriented developments	0	0	0	0	1	2	6	9
No, of buildings with "sky greening"	0	0	0	0	1	1	6	8

floors, an observatory floor at a high altitude provides unique interaction and novel experience, and a unique perspective from which to appreciate the city. In the same building, different from office and living spaces, the observatory floor is open to the public and is usually the focus of the whole project, which brings about economic value that cannot be underestimated.

However, the skybridge seems to be not as prevalent a feature in the world's 100 tallest buildings; displaying no continuity during the past 30 years. In the tallest 101 buildings of 2022, the three buildings with a skybridge in the last five-year period were completed in 2019; all of these are located in China: notably, the Golden Eagle Tiandi (368.1 meters) in Nanjing (see Figure 9) and Raffles City (354.5 meters) in Chongqing (see Figure 10). The skybridge can be regarded as a horizontal space created at a high altitude, in the pursuit of urban vertical development. Usually containing restaurants, bars, and sightseeing spaces in a unique architectural form, the skybridge is a very distinctive area in the building and is attractive to visitors.

Transit-oriented development (TOD) has grown into a highly-valued concept over the years; has seen a relatively significant growth in the last 5 years. The process of high-density urbanization has higher comprehensive requirements



Figure 9. Golden Eagle Tiandi, Nanjing. (Source: https://www.skyscrapercenter.com/building/golden-eagle-tiandi-tower-a/11463)



Figure 10. Raffles City, Chongqing. (Source: https://www.skyscrapercenter.com/building/raffles-city-chongqing-t3n/13610)



Figure 11. Dabaihui Plaza, Shenzhen. (Source: https://www.skyscrapercenter.com/building/dabaihui-plaza/14198)



Figure 12. Huiyun Center, Shenzhen. (Source: https://www.skyscrapercenter.com/building/huiyun-center/29371)

for the public transport system and the transformation of space. TOD is a positive and efficient model that has emerged under this development state. It establishes a complex integrating work, commerce, residence, transportation, etc., to create a more convenient and comfortable urban life experience, and also contrinbutes to efficiency and energy savings. In the world's tallest 101 buildings in 2022, the most recently completed TOD projects are Dabaihui Plaza (375.6 meters, 2021) (see Figure 11) and Huiyun Center (359.2 meters, 2022) (see Figure 12), both located in Shenzhen, a city with a large number of tall buildings. Metro operational mileage is increasing every year in Shenzhen and other major cities in China, and enterprises related to metro operation have become an important real-estate development force.

The following paragraphs categorize the construction of TOD complexes. Tall projects with TOD generally cover multiple business types such as Grade-A office, urban commerce, high-end residential floors, culture and art space, to build a three-dimensional lifestyle to facilitate urban living. As the feature of TOD project is to connect to the urban traffic system, it will bring a continuous stream of people and transport capacity for the building complex, promote commercial prosperity and fuel long-term operation. It is believed that there will be more such cases in the long run.

The development arc of "sky greening" is similar to that of TOD. Supertall buildings aspire to make achievements under the increasingly urgent goal of providing ecologically-friendly, sustainable development. Green walls, sky gardens and other attempts will help improve the quality of the upper spaces in the building and create a high-quality environment. It not only creates a good indoor environment, but also shortens the distance between people and nature, which can compensate for the lack of emotional belonging and place identity in tall buildings. It is worth mentioning that China introduced dual carbon-guiding principles in 2020. Applied to the construction industry, more tall buildings will put emphasis on environmentally friendly design and operation, such as green space and energy-saving technology, so as to satisfy the guiding principle. However, this is not an easy feat. Growing plants at high altitude requires more maintenance as well as a higher investment in technology.

Take Raffles City Chongqing as an example, which integrates the characteristics of observatory, skybridge, TOD and sky greening into one complex. There are eight buildings in the complex. The site has a terrain elevation



Figures 13. The 300-meter-long skybridge at Raffles City, Chongqing. (Source: https://new.qq.com/rain/a/20200924 a0inl500)



Figures 14. The internal space of the skybridge at Raffles City, Chongqing. (Source: Wood 2022)

difference of 30 meters, complicating circulation. The introduction of TOD strategies effectively calms the surrounding traffic. Not only is there a comprehensive transportation hub integrating metro, bus and ferry, but also a traffic diversion system designed to accommodate the site elevation difference, connecting both the upper road and the lower Binjiang Road nearby.

Raffles City's skybridge is about 300 meters long, connecting the tops of four towers of 250 meters' height (see Figure 13). It is so large it can be thought of as the ninth building in the complex. The skybridge gathers the functions of observatory, sky garden, restaurant and hotel lobby, which are open to the public. At the same time, there are a series of facilities only for Raffles members, including an infinity swimming pool and gym (see Figure 14). No matter the TOD design at the bottom of the building or the featured design of the skybridge, from any point of view, the skybridge adds color and distinction to the project, bringing comfort to users, providing a unique feature that should be supportive of the long-term operation of the project. More broadly, it demonstrates the potential to create high-quality vertical living space, harmoniously integrated with the surrounding urban environment, creating a livable urban community, and becoming a symbol of the city.

Conclusion

Supertall buildings are usually city landmarks, which play an important role in the environment of the whole city. The minimum height and average height of the tallest 100 over the world are increasing year by year. However, tall buildings do not always pursue height. They are more concerned about adapting to the needs of current and future urban development, such as efficiency in work and life, contribution to ecological sustainability, to have positive impact on the natural and social environment of the city. It is expected that supertall buildings will not only bring the world a high level, but also a high-quality living environment in the future.

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