

## Article

# Incremental Production of Urban Public Green Space: A ‘Spiral Space’ Building Typology

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**Abstract:** This paper addresses a challenging global problem, insufficient accessible urban public green space, based on building typology. Offering sufficient public green spaces and maintaining the equalities of citizens’ accessibility in high-intensity urban cities has been increasingly challenging. Thus, providing adequate and accessible green public spaces by 2030 is a sub-goal of SDGs No. 11. Solving this urban problem is commonly considered the responsibility of urban planning; however, the potential of buildings is scarcely discussed in academia. Luckily, in the industry, many top architecture firms (studios) have tapped the particular potential of buildings via design practice. This practice-led research aims to understand the efforts made by industrial circles. Based on the fieldwork worldwide, this study proposes a ‘spiral space’ building typology to work as a conceptual framework for this emerging field. The key benefit of this building typology—incremental production of public green spaces—is qualitatively verified, and the good flexibility and international acceptance of this building typology are demonstrated based on global cases. This work could serve as a basis for future research on how buildings could play a greater role in supporting urban sustainability, such as enhancing the residents’ accessibility to public green space in metropolises. In addition, the building typology and corresponding design strategies discussed herein could also serve as references for future design practice for architects.

**Keywords:** public green spaces; sky gardens; practice-led research; urban sustainability; building typology



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## 1. Introduction

### 1.1. Scarcity of Public Green Space in Cities

Urban public green space generally refers to the freely accessible space, which is a public good and dominated by green vegetation [1]. It plays a crucial role in sustaining the quality of urban environments and social systems, and human wellbeing [2], which includes parks, street trees, greenways, private gardens (on the ground), and sky gardens (roof gardens) [3]. Urban public green spaces are commonly regarded as ‘green lungs’ [4], which ‘are essential for functioning the quality of life in cities’ [5]. Plenty of benefits of urban public green space to cities have been revealed, including social, environmental, and economic benefits. Specifically, the benefits cover but are not limited to enhancing social interaction and communication [6,7]; maintaining city dwellers’ mental (e.g., relieving stress [8]) and physical health [9,10]; improving air quality [11] and mediating urban micro-climate [12]; and increasing the prices of real estate as added value [13,14]. When urban public and green spaces are insufficient, a city will not only lose the above gains, but also result in an increased willingness of citizens to move out of the city [15]. Thus, ‘sufficient access to urban green spaces represents a key aspect for adequate living conditions and a healthy environment in urban areas’ [16], and the significance of urban public green spaces is emphasized by SDGs No. 11—sustainable cities and community [17]: ‘By 2030, provide universal access to safe, inclusive and accessible, green and public

spaces' [18]. However, the rapid urbanization and dramatic urban expansion have been rising problems of the squeezing and loss of urban public open and green space, caused by the conversion of public open and green land to residential areas [19,20]. Additionally, the high-density crowded-built community and growing urban populations will further weaken the green space area available per resident and the accessibility of public spaces for urban dwellers [21]. Hence, the scarcity of urban public open and green spaces presents an increasingly serious challenge for contemporary cities [2] and sets up undesirable barriers to urban sustainability [22]. To date, constructing and optimizing urban green space systems is generally regarded as the responsibility of urban planners, and certain efforts have been made to maintain the minimum area per capita, quality, and accessibility of urban green spaces [23–25]. However, in the undergoing densification of urban areas, the provision of adequate green space on the ground is sometimes difficult [26]. With this concern, other greening solutions above the ground, such as partial space of buildings, have become increasingly popular to offer extra accessible public green space. Given an example, sky gardens are a typical solution that has become an integrated part of many buildings, even an urban vocabulary [27], and a vital asset for occupants [23,28]. Hence, great potential in buildings, to deal with the aforesaid high-intensity city problem, is to be tapped, but little attention is given to this in academic circles, resulting in a barrier to fulfilling the potential of buildings in this regard. Interestingly, however, in industry, continued efforts have been made to unfold this potential of buildings. For example, several renowned architectural firms, such as BIG (Bjarke Ingels Group), MVRDV, and SOM, have proposed interesting proposals to heal this problem. Based on the global field research campaign from 2015–2022, this practice-led research works on taking a lesson from the trials and efforts devoted by the industry. Subsequently, this study proposes a building typology named 'spiral space' to establish a conceptual framework for this emerging field, which can serve as a basis for further quantitative studies. The research outcome of this study is expected to serve as a reference for policymakers in urban policy decision making and architects and urban planners in design practices. Typology-based studies on spatial production are generally regarded as a lens to understand the complexity of design, planning, and construction practice [29,30]. Meanwhile, defining building typologies commonly works as a basis for (quantitative) multiparametric analysis [31].

### 1.2. From 'Highline' to 'Skyline'

In Manhattan, New York, one of the most densely populated urban areas worldwide, an ambitious building program is under construction and is designed to extend the 'High Line' into buildings. This case has explored a promising solution to offer more public and green space to cities under high-development intensity. The High Line is widely known as one of the 'most iconic urban public spaces of the early twenty-first century' [32] and was transformed from a former elevated freight rail line [33,34]. The 66-floor skyscraper program is located near The High Line, named 'the Spiral' or 66 Hudson Boulevard. According to its designer, the Bjarke Ingels Group (BIG), the idea of this high-rise building is 'from the High Line to the skyline'. It is situated at the northern end of The High Line and the intersection of the four-acre Hudson Boulevard Park (Figure 1). The Spiral will lengthen The High Line by its cascading linear terraces vertically in a spiraling motion toward the sky. As the appearance of a continuous, green, spiraling pathway winding around the building is shown in Figure 1, a chain of interconnected double-height atria and cascading sky gardens with sizes ranging from 20 to 100 m<sup>2</sup> spiraled up all over the building. These gardens aim to offer accessible outdoor space to every occupant [35]. Those atria and sky gardens link floor-to-floor from the building's bottom to the top, offering a physical activity-based vertical connection as an alternative to the elevator [36].



**Figure 1.** The Spiral and surrounding environment models (modified from [36]).

Meanwhile, The Spiral aims to work as an integrated part of the urban green and blue system (Figure 1) to enhance the network of the urban green space [35] and support the iconic skyline of New York City [36]. As shown in Figure 1, the chain of sky gardens is the key component of ‘The Spiral’ proposal to ‘vertically balance open-space to built-up area ratios within the tall buildings’ [27]. Sky garden generally refers to ‘planted landscapes built above the ground: in intermediate floors of buildings or at the rooftop’ [37]. It is different from the single-roof sky garden (or disconnected and randomly distributed ones) designed in common buildings. It is not hard to find that the benefit of this typology enhances the occupants’ accessibility to public green space, no matter which floor they stay on. In this regard, ‘The Spiral’ has proposed a building-design solution to produce incremental public open and green spaces in high-density urban areas. Moreover, the vertically connected sky gardens, decorating the iconic city skyline, further strengthen the social interactions between dwellers by breaking the isolation between floors.

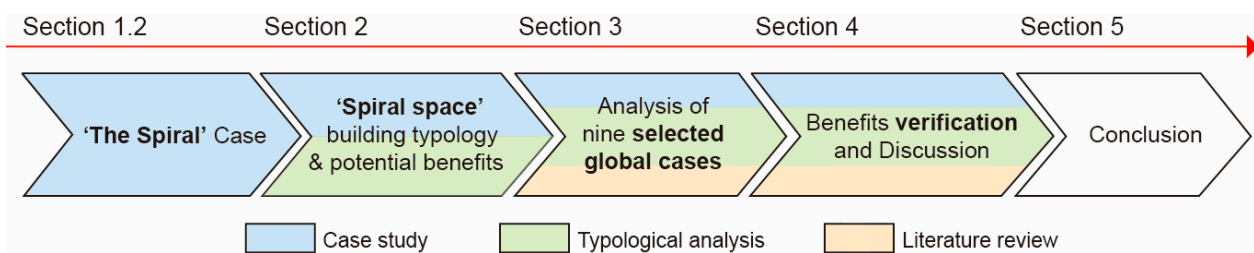
### 1.3. Research Questions and Methods

Discovering the core pattern of existing cases is the foundation to foster reasonable innovations [38]. This study treats The Spiral as a case of the ‘spiral space’ building typology proposed in this study. Refer to Section 3.10 for more details. This practice-led research investigates more typical global cases based on fieldwork (Section 3), to answer the following two research questions:

- (1) Can we qualitatively verify the aforesaid added value of The Spiral as natural, at least as promising, benefits of this building typology to cities, including generating incremental urban green space, etc.?
- (2) If the abovementioned advantages of spiral-space building typology could be regarded as promising, what is its performance in the adaptability of building diversity (e.g., function, size, height, etc.) and acceptance worldwide?

In brief, if the mentioned benefits could be achieved by the proposed ‘spiral space’ building typology, as an architectural design approach, it will enhance urban dwellers’ accessibility to public green space in high-intensity urban habitats. It is also valuable for SDGs (e.g., No. 11 sustainable cities and community) to ‘provide universal access to safe, inclusive and accessible, green and public spaces’ [18]. Field observation-based case studies, typological analyses, and literature reviews [39] are the main research methods used in this study. The remaining text of this paper is organized as follows. Section 2 qualitatively

analyzes the potential benefits of spiral-space building typology to cities, which are mainly based on the case study and typological analysis. Typical global building cases of spiral-space typology are selected and introduced in Section 3. Mainly based on the case study, the proposed added value of spiral space to cities in Section 2 is qualitatively verified in Section 4.1, and its adaptability to building diversity and international acceptance are revealed in Section 4.2. A further discussion is proposed in Section 4.2 and the key lessons learned in this study are concluded in Section 5. The main research methods involved in the main sections are presented in Figure 2 via the corresponding color codes.

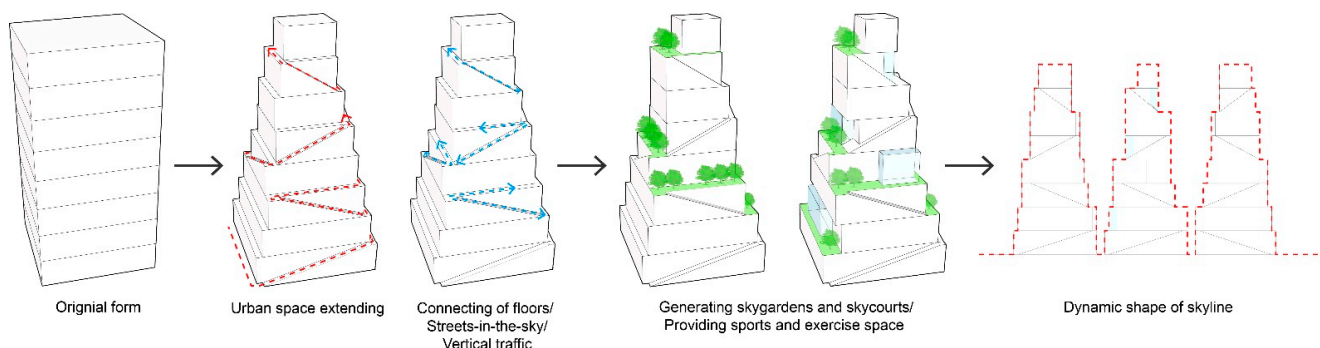


**Figure 2.** The workflow of this study with corresponding main research methods used in the main sections.

## 2. Benefits of Spiral-Space Typology to Cities

### 2.1. Potential Benefits of Spiral-Space Building Typology

As illustrated in Section 1.2, the 'spiral space' (Figure 1) is not hard to observe, which refers to the characteristics of the spiral-space building typology. The key potential contributions of the spiral-space typology to cities are presented in Figure 3, which are as follows: (1) extending urban public spaces into the buildings and broadening available public spaces in cities, (2) connecting adjacent floors vertically to enhance social interactions, (3) generating a series of sky gardens to closely imitate the natural working/living environment, and (4) creating attractive and architectural forms and skylines for cities. Additionally, as presented in Figure 4, this building typology is promising for supporting urban sustainability in the three pillars (i.e., social, environmental, and economic) [40], based on qualitative analysis. The details of urban sustainability are clarified in the subsequent section. To be specific, this building typology could enhance public space accessibility and social interaction (social), mitigate the urban heat island effect (environmental), and impose a positive city brand effect (economic). The cases selected in Figure 4 are introduced in Section 3, and the potential benefits proposed here are qualitatively verified in Section 4.1 based on the field observation of the selected global typical cases.



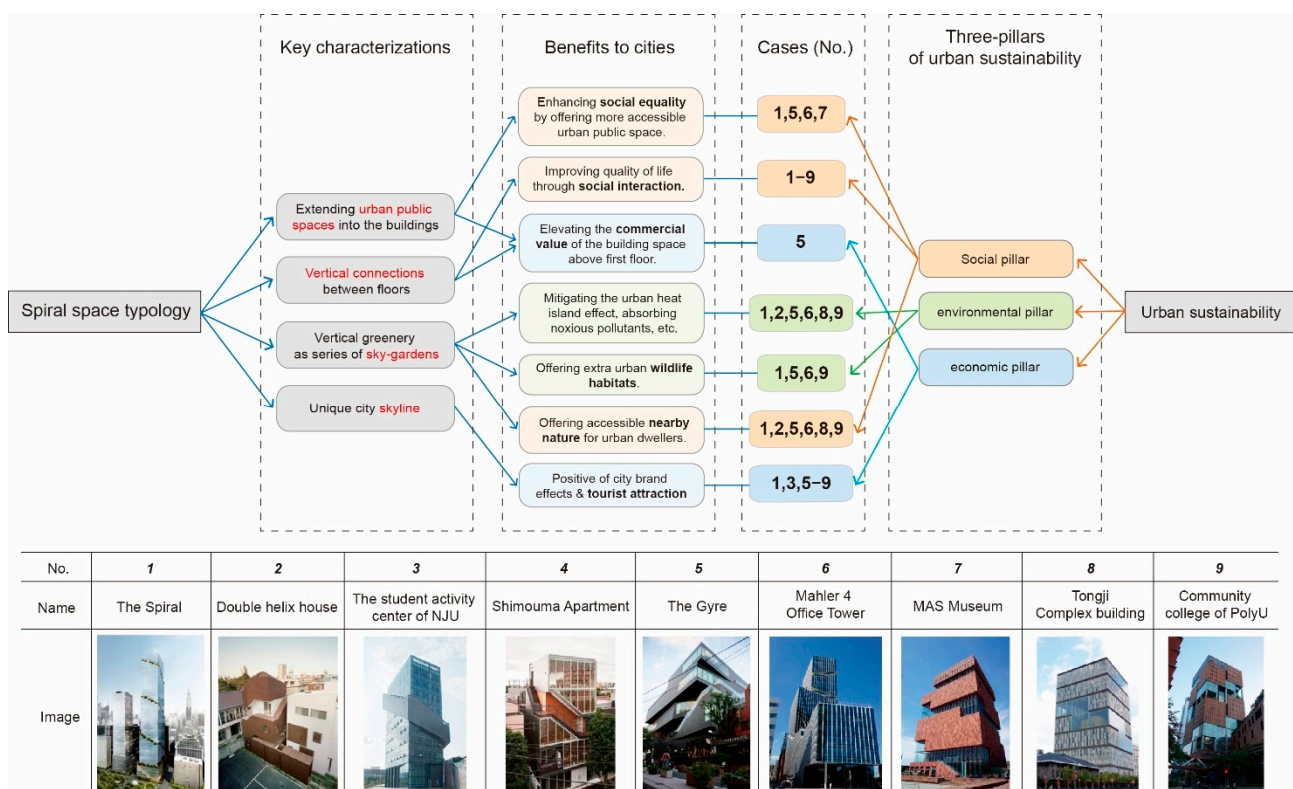
**Figure 3.** Key potential contributions of spiral-space typology to cities.

### 2.2. Urban Sustainability and Sustainable Building

As stated, it has been noted that spiral-space building typology has promising potential to enhance urban sustainability, as presented in Figure 4. Urban sustainability is regarded as 'a key component of global sustainability' [41], which is generally regarded



as a three-pillar concept, to mitigate the (negative) environmental impacts of cities, while elevating both the urban economic and social co-benefits to the maximum. In practice, it is generally interpreted as natural resource protection, economic viability, and social justice and equity [42]. In addition, sustainable building is generally valued as a core part of urban sustainability [43], which is mainly attributed to urban citizens spending most of their time in buildings [44]. Similarly, the three-pillar sustainability, i.e., social, economic, and environmental, also serves as the ‘cornerstone’ for sustainable building assessment [45,46]. As stated, the key interest of this study was to examine the potential benefits of the proposed spiral-space building typology to cities, as visualized in Figure 3. Although once the said benefits are well achieved, the spiral-space building typology might be promising to enhance three-pillar urban sustainability, and it was noted that the evaluation of sustainable buildings is rather complex, which is mainly based on rating tools, such as BREEAM, LEED, CASBEE, EEWH, and ESGB (BREEAM: Building Research Establishment Environmental Assessment Method; LEED: Leadership in Energy and Environmental Design; CASBEE: Comprehensive Assessment System for Built Environment Efficiency; EEWH: Ecology, Energy Saving, Waste Reduction, Health; and ESGB: Evaluation Standard Green Building) [46,47], with index and quantitative evaluation systems [48,49]. Thus, this study only discussed the potential contributions of spiral-space building typology to urban sustainability but leaves the ‘sustainable building’ qualification discussion for future studies.



**Figure 4.** Potential benefits of spiral-space typology and potential connections to global cases. ‘The Spiral’ image in Figure 4 is obtained from reference [36] (BIG official website).

### 3. Global Cases

To qualitatively verify the benefits of the spiral-space typology proposed in Section 2, more typical global cases with certain diversity in functions, sizes, and locations, were selected and investigated to incorporate multiple sources of evidence [39]. As presented in Figure 5, selected cases are distributed in Asia, Europe, and North America, and their basic information is tabulated in Table 1. It is noteworthy that more cases, in addition to Table 1,

can be found worldwide. They include, but are not limited to, the Mahanakhon building, designed by OMA, in Bangkok, Thailand, and Commerzbank headquarters located in Frankfurt, Germany, which is the work of Foster + Partners. A literature review-based pre-selection was conducted in the initial stage to determine the representative ones (i.e., cases in Table 1). This section briefly introduces these cases to lay a foundation for the practice-led verification research in Section 4. In Table 1, ‘floors’ refers to the number of floors (*FNs*) above the ground. The averaged floor area (*AFA*) is calculated as gross floor area above ground (*GFA*) divided by the number of ‘floors’ as Formula (1) for each building to roughly estimate the gross site areas for the nine cases. In addition, the four types of prototypes under this particular building typology—original, convex, shallow concave, and deep concave prototypes—are elaborated upon in Section 3.10.

$$AFA = \frac{GFA}{FN} \quad (1)$$



**Figure 5.** The distribution map of nine global cases.



**Table 1.** The basic information of nice global cases.

Type	Original	Convex	
No.	1	2	3
Name	The Spiral	Double Helix House	The student activity center of NJU
Function	Office	Residence	Office
Location	New York, USA	Tokyo, Japan	Nanjing, China
Architect	BIG (Bjarke Ingels Group)	O+H Architecture	Preston Scott Cohen Inc.
Floors	66 F	3 F	10 F
Gross floor area ( <i>GFA</i> )	264,775.0 m <sup>2</sup>	91.2 m <sup>2</sup>	Around 1950.0 m <sup>2</sup>
Averaged floor area ( <i>AFA</i> )	4011.7 m <sup>2</sup>	30.4 m <sup>2</sup>	Around 195.0 m <sup>2</sup>
Completion	2022 (under construction)	2011	2009

Table 1. Cont.

Type	Original		Convex
Image			
Type	Shallow concave		
No.	4	5	6
Name	Shimouma Apartment	The Gyre	Mahler 4 Office Tower
Function	Residence	Commercial	Office
Location	Tokyo, Japan	Tokyo, Japan	Amsterdam, Netherlands
Architect	KUS	MVRDV	Rafael Viñoly Architects
Floors	5 F	5 F	24 F
GFA	372.2 m <sup>2</sup>	8979.0 m <sup>2</sup>	32,260.0 m <sup>2</sup>
AEA	74.4 m <sup>2</sup>	1795.8 m <sup>2</sup>	1344.2 m <sup>2</sup>
Completion	2013	2007	2005
Image			
Type	Deep concave		
No.	7	8	9
Name	MAS Museum	Tongji Teaching-Research complex Building	Community College of PolyU
Function	Museum	Education	Education
Location	Antwerp, Belgium	Shanghai, China	Hong Kong, China
Architect	Neutelings Riedijk Architects	Jean Paul Viguier	Wang Wei Jen Architecture
Floors	10 F	21 F	19 F
GFA	20,000.0 m <sup>2</sup>	46,240.0 m <sup>2</sup>	26,000.0 m <sup>2</sup>
AEA	2000.0 m <sup>2</sup>	2201.9 m <sup>2</sup>	1368.4 m <sup>2</sup>
Completion	2011	2007	2008

Table 1. Cont.

Type	Original	Convex
Image		

The first image of Table 1 is obtained from wiki: [https://en.wikipedia.org/wiki/The\\_Spiral](https://en.wikipedia.org/wiki/The_Spiral) (accessed on 12 May 2021).

### 3.1. The Spiral

In Section 1.2, an overview of the spiral case was introduced. According to its architect, Bjarke Ingels, The Spiral was generated based on the following idea: ‘from the High Line to the skyline [36]’. This indicates that the main feature of The Spiral is extending urban public green spaces into buildings, as presented by the spiral gardens in Figure 1. Meanwhile, the continuous green spiraling gardens provide readily accessible outdoor space to occupants on different building floors [35] (Figure 1) and connect multiple building levels, which serves as an alternative to elevators, encouraging physical activity and enhancing the interaction among occupants. In addition, the unique building shape of The Spiral also contributes to the presence of the iconic skyline [36] (Figure 1).

### 3.2. Double Helix House

The Double Helix House is located in the Yanaka area, Tokyo. The design is the work of O+H studio. The form of the house consists of a white core of a rectangular block plus a spiral space that tightly intertwines with the white block (Table 1) [50]. The core functional spaces, such as the living room, dining room, kitchen, and bathroom, are distributed in the white block with the spiral space serving as stairs and the study-room.

### 3.3. The Student Activity Center of NJU

The student activity center of Nanjing University (NJU), designed by Preston Scott Cohen, is located at the Xianlin International camp of Nanjing University, Nanjing, China. Similar to the Double Helix House, the building consists of the core office building and the winding spiral space (Table 1). The spiral space functions as fire stairs and connects 3–10 floors [51].

### 3.4. Shimouma Apartment

The five-floor Shimouma apartment designed by KUS is situated in the Setagaya area, Tokyo. It is a residential building with a store on the first floor. A spiral space is carved around the building (Table 1), which works as stairs connecting different floors [52].

### 3.5. The Gyre

The seven-floor shopping center ‘The Gyre’, the work of MVRDV, is located in Omotesando, Tokyo. The architectural form of ‘The Gyre’ is generated by rotating floors at different angles around the central axis. A series of terraces emerge and are subsequently connected by stairs. Finally, two pairs of spiral spaces—two vertical-stepped terraced streets—were created and carved into the diagonal periphery of the building. A couple of the spiral vertical streets in opposite directions (one street ascending and the other descending) are connected to each other at the top floor of the building, which functions as



two vertical-stepped terraced streets for the shopping center, and guides more customers to commercial space above the ground floor (Table 1). The spiral space, coiled on the building, not only offers equal access to all floors, but also produces an iconic and sculptural form of ‘The Gyre’.

### 3.6. Mahler 4 Office Tower

The mixed-use program named the Mahler 4 Office Tower, designed by Rafael Vinoly Architects, is located at the South Axis of Amsterdam, the Netherlands. The building reinterprets a dynamic geometry by exterior fire stairs that wrap around the building and yield an animated urban composition (Table 1). The open stair subtracts a spiral volume from the building and offers a fair-weather alternative to vertical transport to the elevators. The staircases spread from bottom to top and offer the possibility of creating exterior spaces programmed as gardens and outdoor expansion (e.g., small plazas) on each floor. Meanwhile, the staircases also guide a public rooftop terrace on the sixth floor [53].

### 3.7. MAS Museum

The MAS city history museum of Antwerp (MAS Museum) is situated in the old harbor near the city center of Antwerp, Belgium, which was designed by Neutelings Riedijk Architects. The MAS Museum is a sixty-meter-high ‘stacked gallery’, with each floor rotated a quarter turn from the last (Table 1). The ‘vacant space’ generated by the rotating process produces a spiraling space around the core exhibition galleries, as a ‘vertical promenade from the public square to the roof’ [54]. Throughout the glazed spiral space from the ground to the roof, the panorama of Antwerp city unfolds for the visitors.

### 3.8. Tongji Teaching–Research Complex Building

The 21-floor Teaching and Research Complex Building, designed by Jean-Paul Viguier, is located in Tongji University, Shanghai, China. This building comprises seven stacked three-floor L-shaped functional components of the same size. Each component rotates 90 degrees clockwise from the lower one, except the bottom-most one. Stacking and rotating six times, a central atrium accompanied by spiral space is formed (Table 1). Several conference halls, media centers, and public sky gardens are distributed in the spiral space [55].

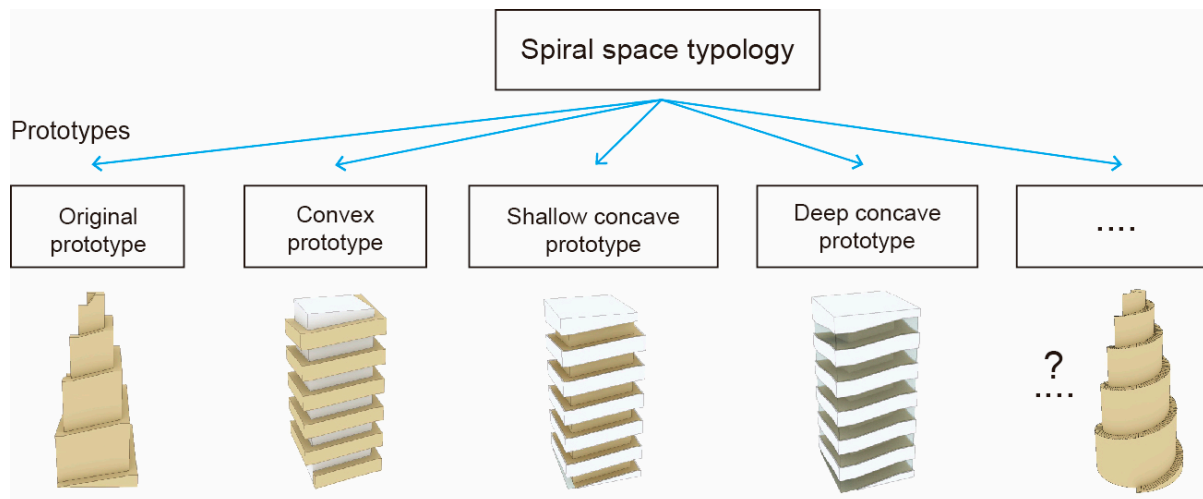
### 3.9. The Community College of PolyU

The twenty-storey Community College of Hong Kong Polytechnic University, designed by the Wang Weijen architecture research group, is situated at Hung Hum, Hong Kong, China (Table 1). This study sought a typology of integrated articulated sky gardens and sky courts for high-rise towers. Different from the typical vertical lift core-dominated vertical campus building, a series of sky gardens or sky plazas were designed and vertically connected to serve as activity centers and circulation systems. The façade of the building also reflects the spiral connection and the solid-void rhythm that was designed [56].

### 3.10. Spiral-Space Building Typology and Prototypes

In this study, a building typology was regarded as a group of building prototypes with similar characteristics, and Figure 6 serves as a reference. Meanwhile, similar characteristics mainly refer to the ‘performance’ of the building in this study, such as making specific contributions, rather than the building morphology. Thus, similarly, the key interest of this paper was the ‘capability’ of the building typology to contribute to urban sustainability (e.g., discussion in Section 4), rather than the particular ‘form’ of spiral-space typology-specific building prototype visualized in Figure 6. In this regard, the spiral-space building typology could be defined as a building typology that creates a spiraling space that allows the public on the ground or occupants in the building to ascend (step by step) toward pre-designed elevated public space, such as sky gardens. In addition, as shown in Table 1, the appearances of cases vary significantly, but can be classified into four main prototypes under the spiral-space typology, based on the key features of architectural form for particular

building cases. Meanwhile, this does not mean that there are only four available spiral-space building prototypes, and more potential candidates satisfying the (spiral-space-building) typology definition could be explored in future design practices, such as a potential fifth (spiral-space-building) prototype, illustrated in Figure 6.



**Figure 6.** Spiral-space typology and prototypes.

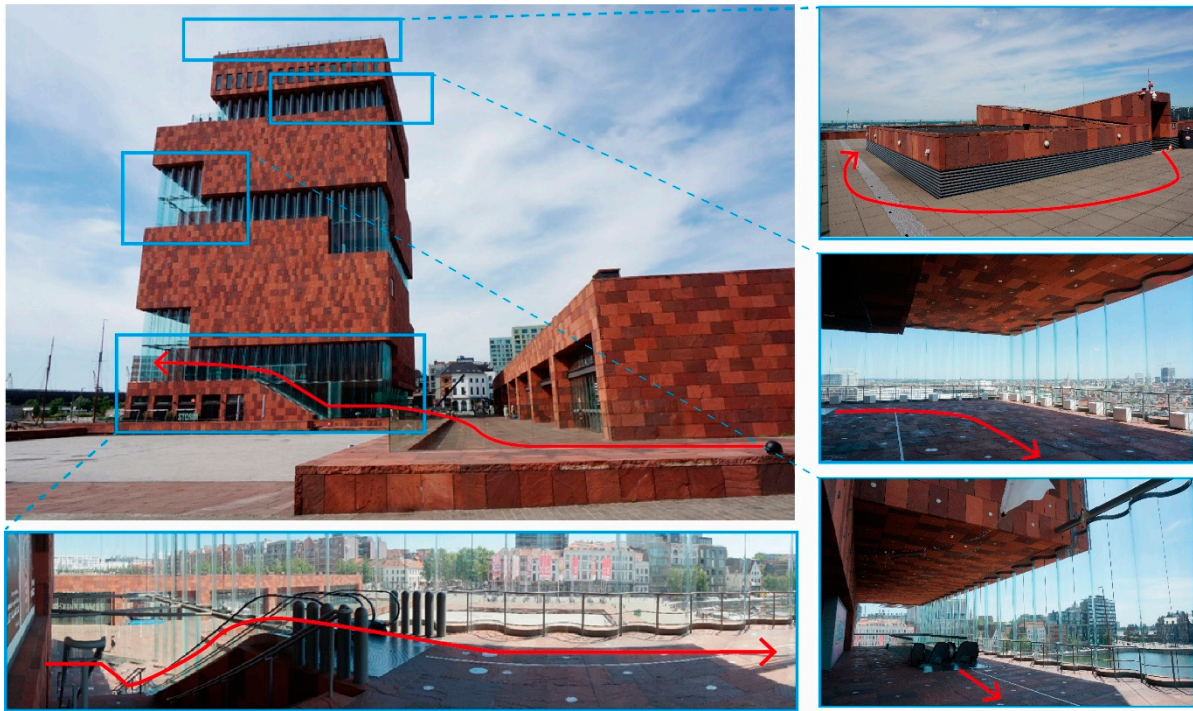
#### 4. Verifications and Discussion

##### 4.1. Verification of Benefits

In this section, the key contributions of spiral-space typology to cities, discussed in Section 2, were qualitatively verified by fieldwork research on the selected global cases (Table 1) and related literature.

##### 4.1.1. Incremental Production of Urban Public Space

More innovations in design are needed to deal with the overcrowding feeling and anxiety of scarce public space in increasingly denser cities [53], since urban public space is crucial in daily city life for relaxation, entertainment, social connection [57]. The integration of publicly accessible amenities into buildings is a desirable approach to expand the use of a given building to ever-broader segments of the surrounding urban populations, creating a sense of community that centers on the public amenity [53]. To clarify the incremental production of urban public space characteristics in spiral-space typology, two cases out of nine in Table 1 were discussed. For example, stairs (and escalators) in the spiral space take visitors across nine floors to the top of the MAS museum, and it is accessible to the public 24/7 and for free. Hence, the 5 m and 11 m high spiral spaces wrapped by the corrugated glass, with a constantly changing city view, and the roof terrace on the top with a 360-degree view of the city, serve as parts of the city's public space, as shown in Figure 7. As the designer of the MAS museum said: 'it is a public street that you can always go in to have meetings and to enjoy the panoramic view' [58]. Similar to the MAS museum, the spiral space in the Mahler 4 office tower also offers 'accessible rooftop public terraces' [53]. The designer, Rafael Viñoly, explored how to fold the public on the ground into a tall building, and successfully enhanced public space at a height, advancing the interaction and dialogue between buildings and the public [53]. As illustrated in Figure 8, a rooftop, public sky garden of more than 300 m<sup>2</sup> on the sixth floor is opened to society, at least in the design stage, as confirmed by the designer Rafael Viñoly, in his paper: 'The staircase is designed to provide access to a possible rooftop public terrace on the sixth floor' [53].



**Figure 7.** The public space in the MAS museum.

#### 4.1.2. Enhance Social Interactions by Connections between Floors

The research has suggested that planning and designing public interactive spaces can enhance social connections [59,60]. As shown in Figure 3, another key feature of the ‘spiral-space’ typology is the vertical connections of different heights. The vertical connections contribute to breaking insulation between floors and interconnecting adjacent floors. As visualized in Figure 9, The Spiral, designed by BIG, explores the potential of connecting multiple levels by inserting spiral sky gardens (space) to encourage interactions among the occupants [35]. As presented in Figure 9, The Spiral not only breaks the isolated stories, but also offers helpful connections to sky gardens for the occupants on different floors. Collaborating with sky gardens, the vertical traffic path, generated by the spiral space also contributes to a healthy lifestyle for inhabitants by encouraging physical activities and providing streets-in-the-sky as exercise (or sport) yards. As an additional alternative to the vertical-traffic approach, it can also serve as open-air fire stairs as a fair-weather alternative to elevators with fresh air and the open view to the surrounding scenery, such as in the cases of the Shimouma apartment and the Mahler 4 office tower (Figure 8), or enclosed (fire) stairs in the Double Helix House and NJU student activity center (Figure 10). For commercial buildings, the spiral space also supports the engagement of more customers with the second floor and above, increasing the commercial value of floors above the first floor (e.g., third floor and above) by enhancing their (direct) accessibility from the ground. For example, in The Grey designed by MVRDV, two vertical-stepped terraced streets, generated by spiral space, strengthened equal accessibility to all floors (Figure 11). The spiral space applied in The Grey ‘produces a highly iconic and sculptural figure and attracts and invites people, not only at the street level, but also towards destinations higher up’ [61], and ‘explores its various levels and terraces, and the shops within’ [62], as illustrated in Figure 11.



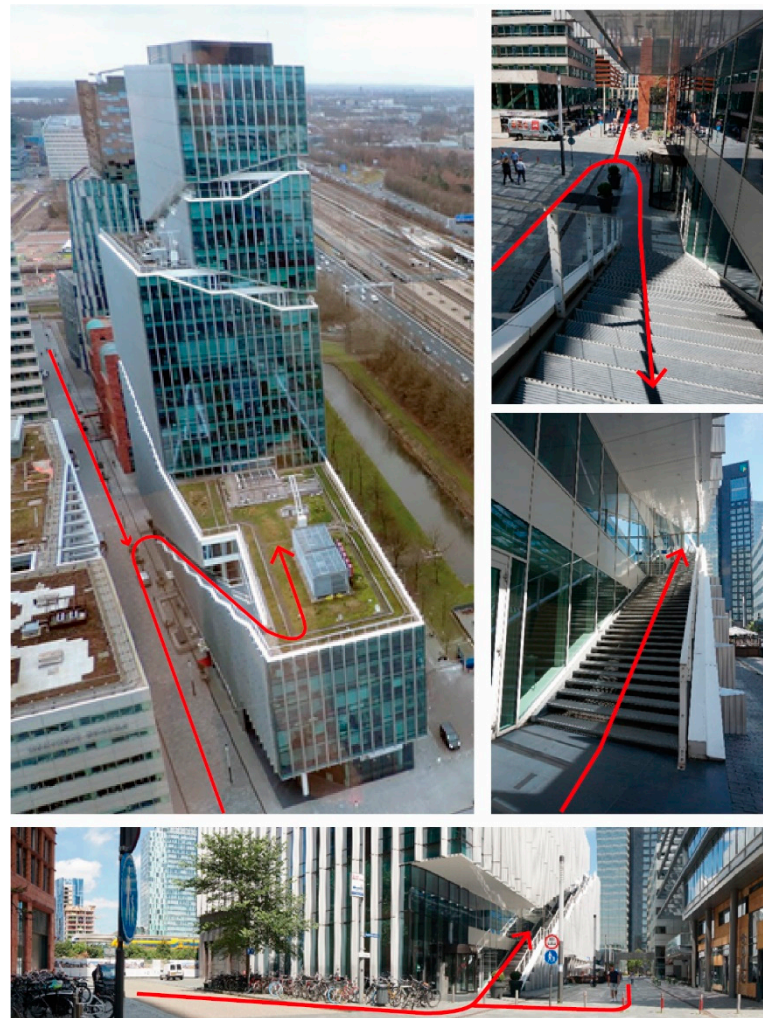


Figure 8. The public sky garden of the Mahler 4 office tower.

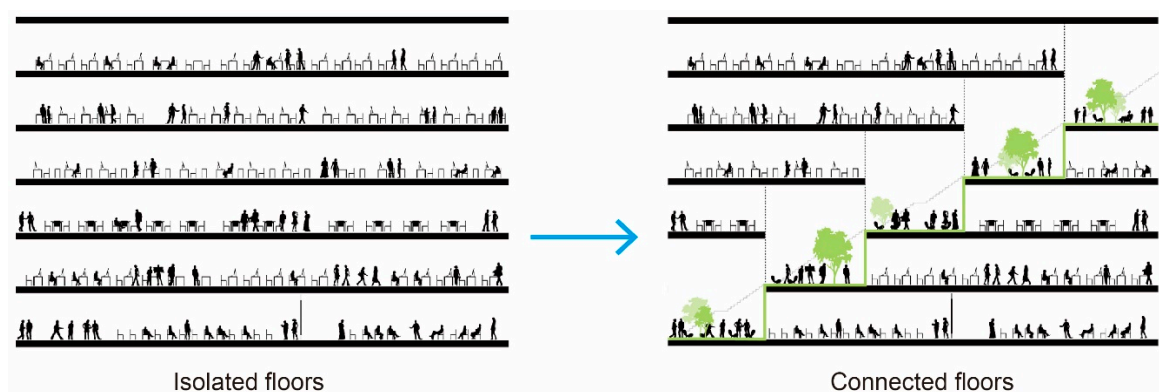
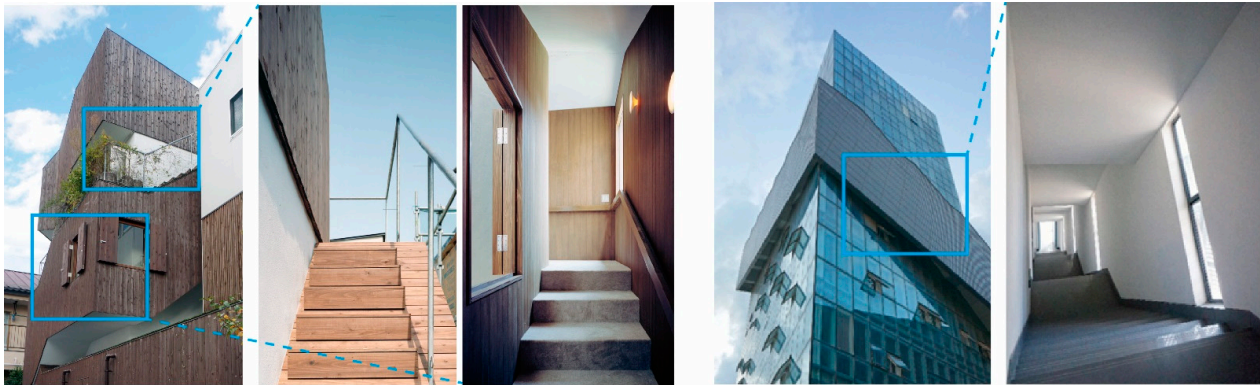


Figure 9. The 'connected floors' concept of building (modified from [36]).

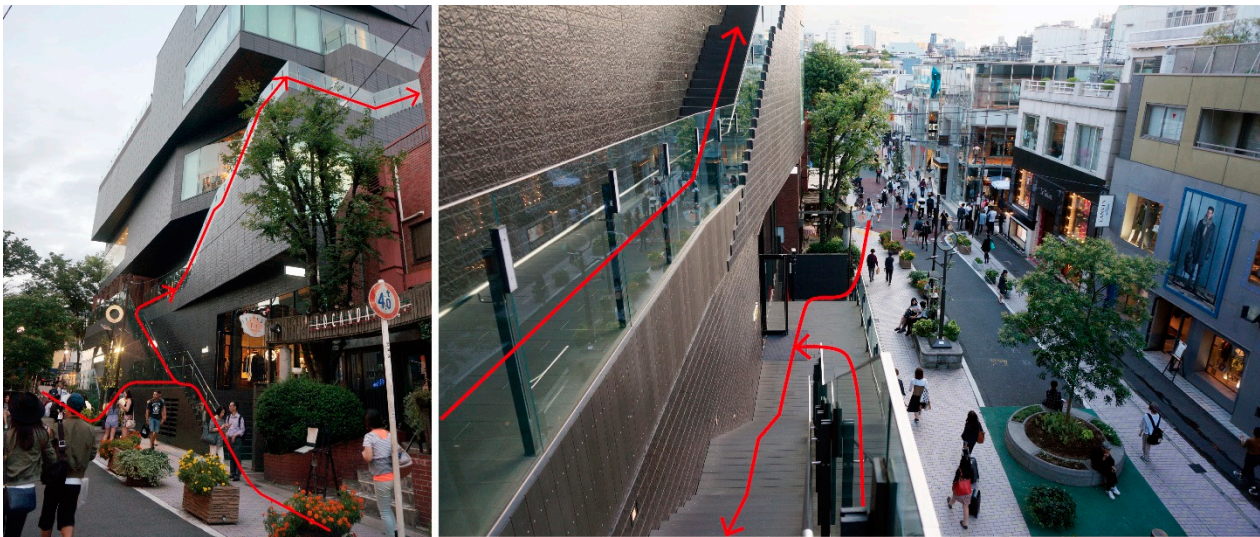
#### 4.1.3. Spatial Production of a Chain of Sky Gardens

The sky-gardens have become an extended urban space vocabulary and could solve the problem of insufficient communal spaces in densely populated cities by offering an 'external environment' indoors [27]. Treating sky gardens in buildings as 'public space' is deemed a promising new urban planning and design strategy [64], for example, the following cases have been discussed: Walkie Talkie Tower, London, UK [64,65] (Figure 12), and Pinnacle@Duxton and SkyVille@Dason, Singapore [27,66,67] (Figures 13 and 14).

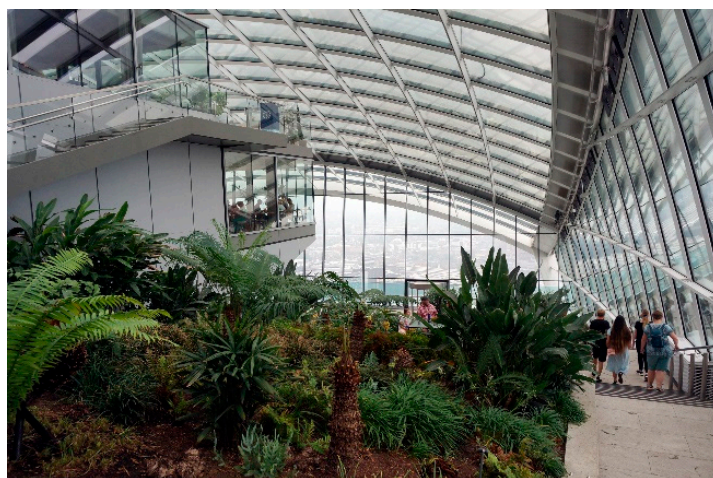




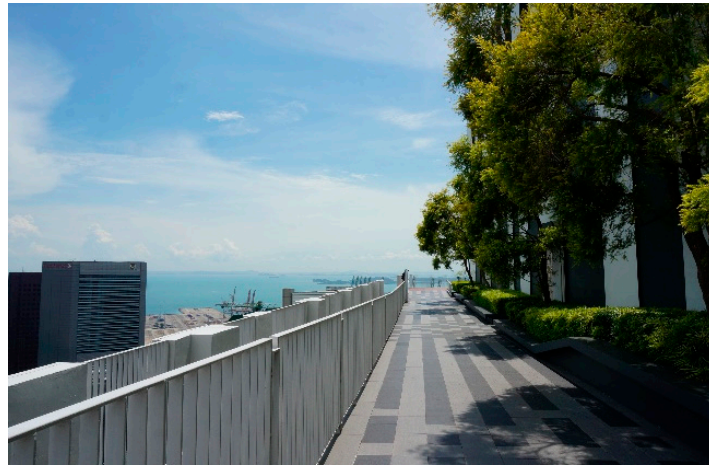
**Figure 10.** The stairs in spiral space of two cases; Double Helix House (left) and NJU student activity center (right) (the second and third images from [63]).



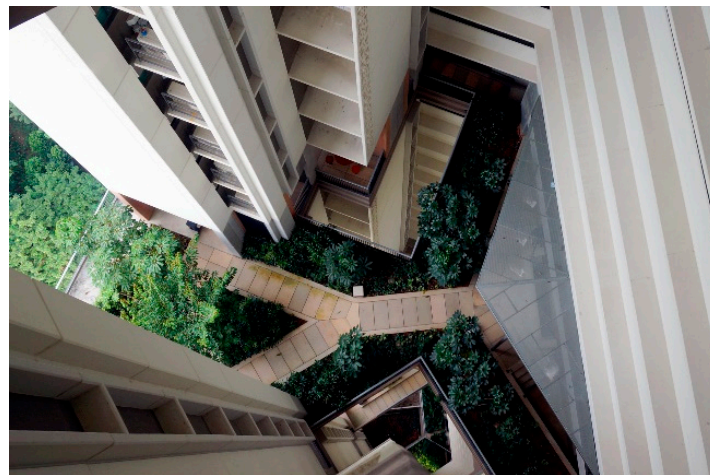
**Figure 11.** The relationship between The Grey and the adjacent commercial street.



**Figure 12.** The sky garden on the top of the Walkie Talkie Tower, London, as ‘public space’ with planning permission.



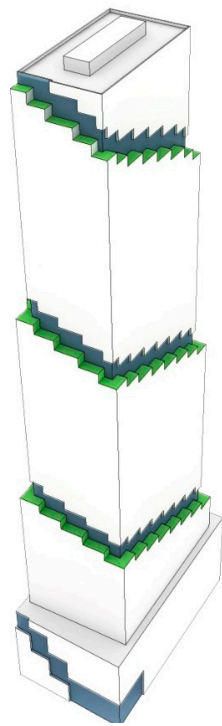
**Figure 13.** The public 50th-story sky garden on the roof of Pinnacle in Duxton, Singapore, with a panoramic view of Singapore city.



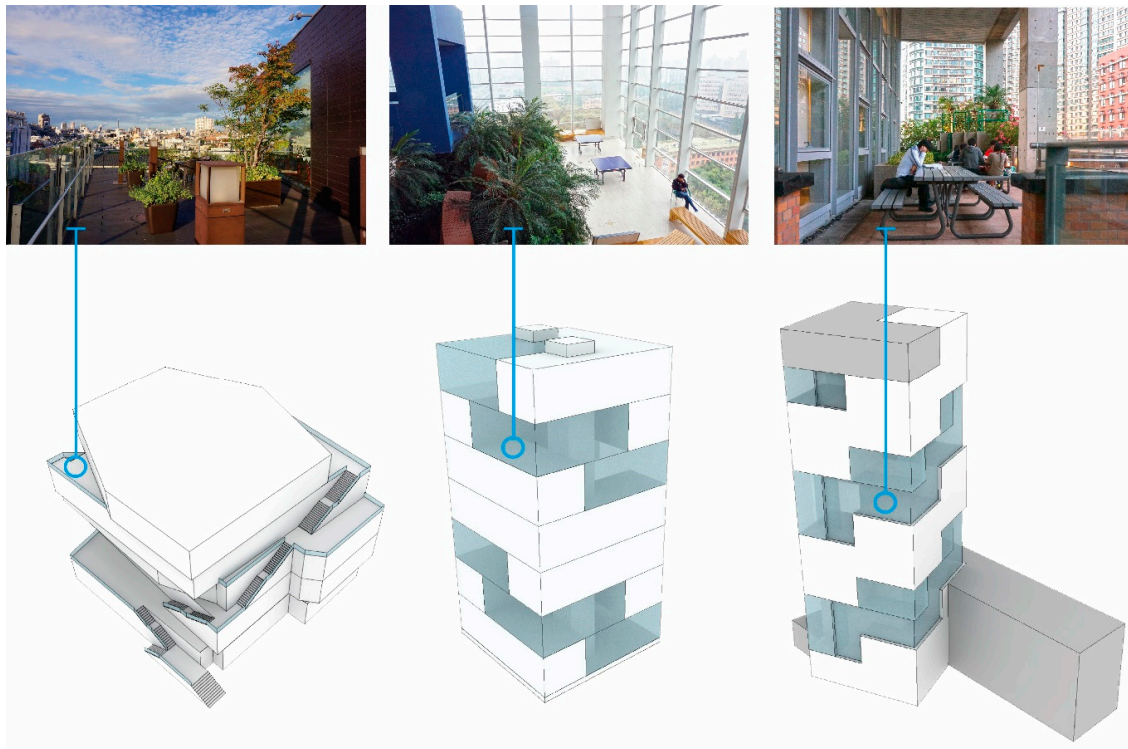
**Figure 14.** The sky gardens in the SkyVille @ Dason, Singapore, as public accessible green space.

Unlike the cases mentioned above, which require elevators to reach the public sky gardens, the spiral-space building typology allows the extension and integration of urban space into buildings via embedded spiral paths, ultimately creating more accessible public space for citizens. Meanwhile, the spiral space itself could also serve as a chain of sky gardens [35], such as ‘The Spiral’ case (Figure 1). As presented in Figure 15, a chain of sky gardens could be naturally generated by this building typology, and this potential has also been reached in most cases (Table 1). Figure 16 illustrates the chain of series sky gardens distributed in The Grey, Tongji Teaching–Research Complex building, and Community College of PolyU. Sky gardens offer a more informal gathering area for meetings, events, and recreational activities, and encourage people to stay for longer periods of time within buildings. The sky gardens’ integration increases greenery coverage and contributes to recreating a balance between open space and built areas, ultimately enhancing the overall occupancy satisfaction of buildings [27,68].





**Figure 15.** The chain of sky gardens in ‘The Spiral’.



**Figure 16.** Sky gardens in The Grey (**left**); Tongji Complex building (**middle**); and Community College of PolyU (**right**).

In general, it could be concluded that the deep concave prototype has an enhanced capability to offer more public space (or sky gardens) to cities, owing to its spatial characteristics with enlarged spiral spaces compared to the rest of the prototypes presented in Figure 9, such as the Tongji Complex building and the Community College of PolyU in Figure 16. However, it is also noteworthy that the shallow concave prototype, such as

‘The Grey’ (Figure 16) and the Mahler 4 office tower (Figure 8), could offer several enlarged platforms (sky gardens) as an integrated part of the ‘spiral space’ itself.

#### 4.1.4. Unique City Landmark and Skyline

As visualized in Figure 3, it is not hard to observe that the spiral-space sculpts buildings into dynamic forms, which reshapes a rigid block into a dynamic-rotation shape, conveying a dynamic image with a sense of impressive mobility. In this regard, spiral space not only contributes to a unique form of building landmark, but also leads to an iconic impression of buildings and distinctive skylines for cities. For cities, distinctive skylines can enhance positive city-brand effects having a crucial positive influence on tourist attractions [69], since the skylines can evoke associations with particular cities [70]. Meanwhile, for an individual building, a unique building form could also gain additional economic value. For example, as mentioned in Section 4.1.2, the highly iconic silhouette and sculptural figure of The Grey, shaped by the spiral space, attracts and invites people to access it, making it a successful commercial building [61].

#### 4.2. Verification of Adaptability and Applicability

Based on the discussions presented in Section 4.1, it is not hard to present a positive response to the first research question. The (promising) benefits of spiral-space typology go beyond offering incremental public green space to the others, such as enhancing social interactions. To answer the second research question, a three-dimensional comparison is visualized in Figure 17, indicating that the nine global cases vary significantly both in function and scale. Specifically, spiral-space typology has been applied in different architectural function types, official, residence, commercial, museum, and educational buildings, demonstrating its broad applicability in the diversity of building functions. In addition, the variation in the averaged floor area (AFA) and floor number (FN) values, quantitatively show that the building scale also considerably fluctuates in the cases (Figure 17). For international acceptance, as indicated in Figure 5, the nine cases of spiral-space typology are widely distributed worldwide. Figure 18 further illustrates where the design institutions of nine cases are based, revealing a rich internationalization of those design institutions. Therefore, we may proceed from the above-mentioned fact to the conclusion of relatively good performances of spiral-space typology in building-diversity adaptability and international acceptance. This conclusion also leads to a positive answer to the second research question, at least a promising positive one.

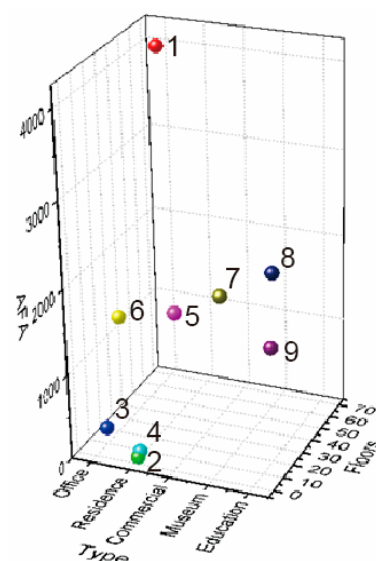


Figure 17. The comparison of nine cases in three dimensions (No. is in line with Table 1).





**Figure 18.** The distribution of design institutions of nine cases (No. is in line with Table 1).

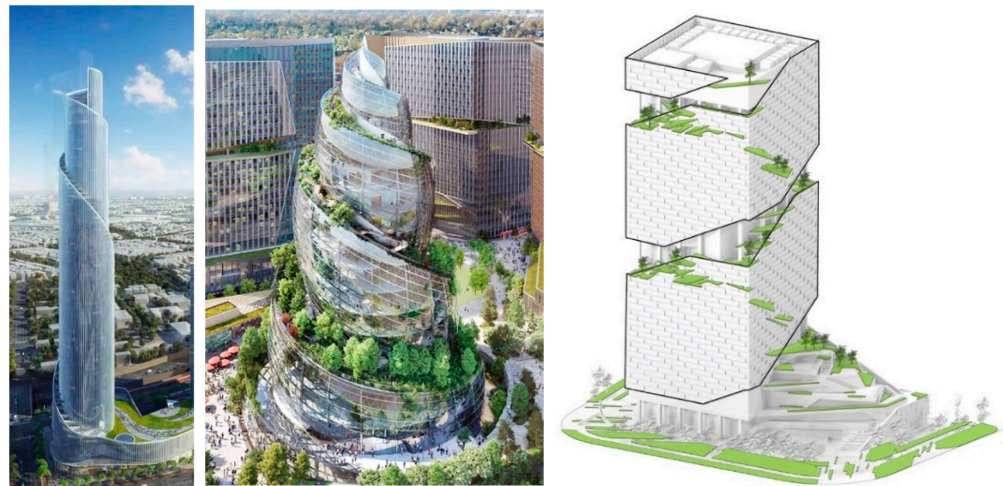
#### 4.3. Discussion

As stated in Section 3.10, the reification of several prototypes, under spiral-space typology, was proposed to classify the studied cases (Table 1). In other words, the aim of the prototypes discussed in Section 3.10 was to serve as a basic outline for understanding the ‘abstract’ concept of spiral-space typology in this study and for future works. The ‘capability’ of spiral-space typology (i.e., contributions to cities) was the key interest of this study, rather than building morphology. Thus, more possibilities regarding building morphology were expected, as the reserved ‘unknown’ prototype illustrated in Figure 6, as supplements. Some recent proposals from well-known design studios (e.g., KPF, SOM, and NBBJ) were observed (Table 2); most of the proposals are under construction and will be built up in 2025. Based on the classified prototypes illustrated in Figure 9, those proposals might vary somewhat in building morphology, which was not of key interest. In contrast, the function of this building typology is reserved and will make a certain contribution to citizens, such as incrementally generating public green space in cities.

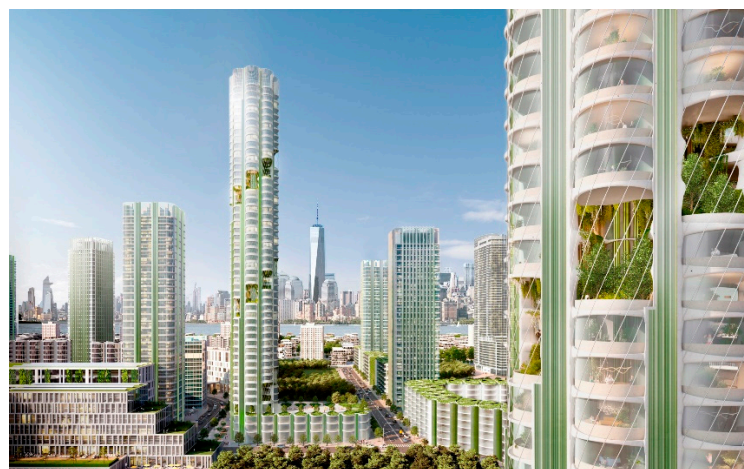
**Table 2.** Some typical recent proposals under spiral-space typology [71–74].

Name	Location	Status	Expected Completion	Designer	Height (m)	Floors	AFA (m <sup>2</sup> )	Function
Azrieli Spiral Tower	Tel Aviv, Israel	Under construction (from 2019)	2025	Kohn Pedersen Fox Associates (KPF)	323	91	1590	Mixed-use (office, residential, hotel, retail space)
The Helix (Amazon Headquarters)	Arlington, U.S.A	Under construction (from 2022)	2025	NBBJ	107.4	22	1182	Office
Vivo Headquarters	Shenzhen, China	Under construction (from 2020)	2025	NBBJ	150	32	3030	Office
W350 Tower	Tokyo, Japan	Proposed in 2018	2041 (Groundbreaking in 2024)	Nikken Sekkei Ltd.	350	70	6500	Mixed-use (residential, office, and retail space)
Urban Sequoia	—	Proposed in 2021	—	SOM	—	—	—	Mixed-use

For instance, the ‘The Helix’ project (Figure 19) was designed for Amazon’s headquarters in Virginia, United States. The spiral outdoor pathways wrapped around the exterior of the building serve as ‘woodlands’ for employees to perform exercises and communicate, which will be opened to the public for at least two weekends per month, as Amazon confirmed to CNN [75]. In addition, at the recent UN Climate Change Conference (COP26), SOM proposed ‘Urban Sequoia’ [76] (Figure 20) for sustainable cities. Similarly, a wooden super-high-rise building proposal named W350 building, was offered by Nikken Sekkei Ltd. to ‘transform city into forest’ [74], which will start construction from 2024 in Tokyo (Figure 21). These forthcoming cases could be interesting cases for future studies. It is interesting to note that the additional five cases, as summarized in Table 2, have extended the possibilities of building prototypes under spiral-space typology, such as the Azrieli Spiral Tower and ‘The Helix’, which could be regarded as the fifth potential building prototype visualized in Figure 6. Thus, as stated in Section 3.10, building morphology is not the key interest of spiral-space typology, since there are approximately ‘endless’ potential building prototypes that could satisfy the definition of spiral-space typology that can generate a spiraling space, guiding citizens to move stepwise toward pre-designed, elevated, public sky gardens.



**Figure 19.** Three proposals under construction: Azrieli Spiral Tower (left), The Helix (middle), and Vivo Headquarters (right) [71–73] (KPF and NBBJ official website).



**Figure 20.** ‘Urban Sequoia’ proposal [76] (SOM official website).



**Figure 21.** W350 Tower plan [74] (Nikken Sekkei LTD. official website).

Although a certain number of benefits of spiral-space typology to cities have been observed (Section 4.1), it does not encourage the overuse of this building typology, and careful ‘deliberation’ before its application is needed. The main reason is that the application of spiral-space typology might raise challenges for privacy protection, construction complexity, and building energy efficiency. Specifically, compared to ‘normal’ buildings, spiral-space typology might increase the risk of privacy protection, especially in rooms or spaces near the spiral spaces. Thus, it requires architects to determine a good layout design (e.g., public/private functional sub-areas) and apply specific design strategies or techniques (e.g., setting bushes to block the view). In addition, the safety issue could be another concern or challenge. Given an example, for the Mahler 4 office tower discussed in Section 4.1.1, in the design stage, ‘The staircase is designed to provide access to a possible rooftop public terrace on the sixth floor’ [53]. However, based on the author’s investigation conducted in July 2020, a glass door was installed to block public access to the said public garden due to safety reasons, based on the responses of the receptionist in the Mahler 4 office tower. Thus, it is acknowledged that the public-space design in buildings might encounter unknown challenges, and more efforts might be required to maintain the accessibility of public sky gardens. Moreover, the ‘irregular’ building form might increase the cost of building design, construction, and maintenance due to its complexity. In addition, the enlarged building’s shape factor ( $F_s$ ) by the ‘unique’ form might weaken the buildings’ energy efficiency, leading to increased energy consumption. The building-shape factor is generally defined as ‘the ratio between the envelope area of the building ( $A$ ) and the inner heated volume of the building ( $V$ )’; a low-shape factor ( $F_s$ ) indicates a compact building shape and lower heat-transfer rate through the whole building envelope [77].

Nevertheless, energy consumption is not the only concern of sustainable buildings, and a set of solutions, such as enhanced insulation material (layers) in building envelopes, are available to mitigate the negative impacts of this disadvantage. Most importantly, the limited ‘flaws’ cannot hide the ‘charm’ of this building typology, owing to its social, environmental, and even economic contributions to urban sustainability as discussed in Section 4.1 and visualized in Figure 4. Hence, based on this qualitative study and moving toward quantitative research, to identify the requirements, the suitable scenario of using this typology based on interdisciplinary multi-objective optimization could be an interesting topic for future studies. For example, future quantitative studies on the synthetic effects of the mentioned pros and cons of this building typology on cities will be interesting and valuable. The multiple objects could include merits, such as enlarged public space accessibility, enhanced social interaction, and disadvantages (e.g., increased building energy consumption). Interdisciplinary multi-objective optimization research has become popular in recent years within engineering, social science, and design [78]. In addition, based on the analysis of the typical global building cases, the discussion in this section initially (qualitatively) verified the proposed potential benefits of the spiral-space building typology



to cities to a great extent (Figure 4). Additional analysis to quantitatively specify the degree of the said benefits could be conducted in the future. Moreover, similarly, although the potential for the incremental production of urban public space was qualitatively verified in this study, the contribution degree of this building typology to SDG, compared to the classic building typologies, still requires a quantitative investigation.

## 5. Conclusions

In summary, based on the fieldwork conducted worldwide, this study proposed a building-typology solution as a ‘supplementary measure’ for sustainable urban planning to handle the problem of the scarcity of urban public open and green spaces in contemporary metropolises, which is a widely reported, international, common problem. Moreover, the additional benefits of this building typology to cities were observed, such as enhancing social interaction among citizens. Most importantly, this typology showed a certain level of adaptability to building diversity, such as building function, size, and height, and global acceptance under different cultures, e.g., in Asia, Europe, and North America. These observations might prove that this building typology is a promising solution, as a response from the building-design level to respond to the urban problem of poor accessibility of urban public open and green spaces, as an ‘additional strategy’ to incorporate it with urban planning practices. As stated, solving the aforesaid urban problem is one of the sub-goals of SDGs No. 11 sustainable cities and community: ‘By 2030, provide universal access to safe, inclusive and accessible, green and public spaces’ [18]. Thus, understanding this building typology and realizing how to take advantage of this typology in practice is meaningful for supporting urban sustainability.

The author suggests that the building form of spiral-space typology is not the key interest and should not be a barrier to future research. As stated, the abstract concept of spiral-space typology could be ‘crystallized’ as numerous building prototypes regarding the building form. Going beyond building morphology, more attention should be paid to the strategies offered by this typology, such as extending or generating urban public and green space in buildings and enhancing social interaction by vertically connecting different building floors. The author argues that if any building approach could offer the abovementioned benefits to cities, it could be regarded as this building typology. For instance, the two cases under construction (i.e., Azrieli Spiral Tower and The Helix) have expanded the spiral-space building prototypes to an additional fifth one, as an additional one to the four prototypes previously mentioned in this study original, convex, shallow concave, and deep concave. Additionally, this study could also be an example for future research that would focus on how buildings in cities could support urban sustainability in a way that is commonly overlooked, which could be quantitatively investigated further in future studies.

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