Elevating the public realm: a framework for designing resilient urban green spaces in hyperdense cities

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Research

Elevating the public realm: a framework for designing resilient urban green spaces in hyperdense cities

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Abstract
This study examines the critical role of elevated urban spaces in fostering urban resilience and enhancing public well-being in the post-pandemic era. Through a detailed literature review and contextual analysis, the research explores how these spaces address the evolving needs for social interaction, public health, and mental wellness in urban design. Focusing on London, with comparisons to international examples such as Singapore, the study presents findings from sixty-six semi-structured walk-along interviews conducted at the Sky Garden and Crossrail Place Roof Garden. Data analysis reveals both the challenges and guiding principles for designing resilient elevated urban spaces. Key areas for improvement include accessibility, circulation, aesthetic integration, and management strategies. The findings emphasise the value of these green spaces in densely populated cities, as they provide vital recreational areas that support the mental and physical health of residents. This research offers a structured framework for embedding elevated green spaces into high-density urban environments, enhancing both resilience and liveability. The study delivers actionable insights for urban planners and policymakers, outlining a nuanced approach to designing sustainable, adaptable green spaces.

Highlights

- Elevated urban green spaces promote health, well-being, and urban resilience in densely populated cities.
- Case studies show how thoughtful design boosts accessibility, social interaction, and environmental benefits.
- This framework helps urban planners create adaptable, sustainable green spaces for future urban challenges.

Keywords Urban resilience · Elevated urban spaces · Post-pandemic urban design · Public health in urbanism · Biophilic design

1 Introduction

The twenty-first century has marked an unprecedented rise in global urban populations and accelerated urbanisation. Since 2007, over half of the world's population resides in urban areas, a figure projected to increase to 66% by 2050, with over six billion people living in urban environments [1, 2]. This intense urban growth, with an approximate

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increase of 1.4 million people weekly, introduces significant pressure on urban infrastructure and the availability of public spaces [3, 4].

This rapid urbanisation, combined with population density, has led to the emergence of various hybrid spatial typologies, including elevated urban green spaces such as rooftop gardens, sky gardens, and elevated parks [5, 6]. Traditional ground-level green spaces alone are insufficient to meet the social, psychological, and environmental needs of urban dwellers, necessitating innovative approaches to urban resilience and liveability [7, 8]. Elevated green spaces offer potential solutions, reintroducing natural elements into densely populated urban landscapes and addressing the scarcity of accessible green spaces in hyperdense cities [5].

However, designing and managing elevated urban spaces in such dense environments present unique challenges. These spaces require careful consideration of accessibility, social interaction, biophilic integration, and public health needs, particularly in light of the COVID-19 pandemic [7, 9]. The pandemic underscored the importance of adaptive and health-focused design approaches, which support both resilience and public well-being in urban areas [5, 7].

This study critically examines the challenges and opportunities associated with elevated urban spaces in London, using the Sky Garden and Crossrail Place Roof Garden as case studies. The primary aim is to propose a framework to inform the design and management of resilient elevated green spaces in hyperdense urban areas. By doing so, this study aims to support urban planners and policymakers in creating spaces that enhance urban resilience, social inclusivity, and public health.

1.1 Research objectives

- To identify the primary challenges and limitations of elevated green spaces in hyperdense urban environments.
- To evaluate the design components critical for elevated green spaces, including accessibility, publicness, circulation, and biophilic elements.
- To analyse the impact of the COVID-19 pandemic on the design and management of elevated green spaces.
- To develop a framework that guides the design and management of resilient elevated spaces, addressing the evolving needs of urban populations.

This study's findings offer actionable insights and guidelines for designing elevated green spaces that are resilient, adaptable, and capable of meeting the demands of urban living in an era of heightened public health awareness.

2 Literature review

2.1 Historical evolution of elevated urban spaces

Elevated green urban spaces represent a novel typology of public spaces, characterised by their elevation above ground level and private ownership and management [9, 10]. Unlike traditional public open spaces such as city squares and parks, these hybrid spaces possess distinct attributes and regulatory frameworks [4, 5]. The urban landscape has witnessed the rise of various hybrid spatial forms, including elevated and multi-level spaces that integrate natural elements. Modern urban settings feature pedestrian bridges, shopping malls, and transport interchanges combined with green spaces, leading to the development of sky courts, sky gardens, and sky parks [11, 12].

Since the 1880s, the emergence of tall buildings within urban environments has been primarily an economic response to the need for centralising workers on valuable city centre land, close to high-quality metropolitan transport, and generating profit from development [4, 13]. However, tall buildings have often been associated with worsening psychological and social issues due to the lack of active open spaces, which are essential for providing ventilation, natural light, and opportunities for social interaction [10, 14].

In the twentieth century, the influential architect Le Corbusier significantly advanced this concept in his manifesto, underscoring the rooftop as a vital element of architectural design [4, 15]. By raising the building above ground level, he created opportunities for open recreation and enhanced light and ventilation. This idea is evident in his designs for

Villa Savoye and Unité d'Habitation, which featured rooftop gardens and other green spaces [16, 17]. Even today, visitors can enjoy a walk on the roof of the Unité without any payment or reservation.

While Le Corbusier's vision of integrating communal spaces and services into vertical buildings was revolutionary, its implementation in the Unité d'Habitation in Marseille has been only partially successful. The intended bustling public shopping street became limited to a small bakery and supermarket primarily used by residents, due to its hidden location within the block [4, 18]. Consequently, the remaining shop spaces were converted into 'boutique offices'. Additionally, the central corridor design of the residential floors lacked natural daylight, resulting in a dim and uninviting interaction space, unlike the office and hotel floors which have side corridors with daylight [19]. These limitations highlight the complexities of fully realising the potential of vertical urban spaces in tall buildings and underscore the importance of careful consideration of design, location, and functionality in their development.

Building on these historical precedents, architect Ken Yeang advanced the concept of elevated urban spaces by making them a central and active component within tall buildings [20]. Yeang recognised their importance not only for social interactions but also for their potential environmental benefits [21, 22]. As a prolific author on the subject of green or 'bioclimatic skyscrapers', Yeang has significantly influenced and inspired a generation of architects and students. These advancements highlight the evolution of elevated urban spaces and sky gardens, showcasing their integration into contemporary architectural design and urban planning [10, 23].

Despite the historical significance of elevated urban spaces, their successful implementation in tall buildings remains challenging [4, 9]. The lack of active open spaces in urban environments exacerbates psychological and social issues, underscoring the need to thoroughly understand the relationship between the built environment and human well-being [7]. Although Le Corbusier's Unité d'Habitation is a pioneering example, it has only partially succeeded in realising the full potential of elevated urban spaces. The limitations and challenges in creating such spaces highlight the importance of carefully considering design, location, and functionality for their successful integration [5].

Building upon these historical developments, the role of elevated urban spaces in hyper-dense urban environments has expanded beyond aesthetic and recreational functions. Contemporary applications require these spaces to support environmental sustainability, social integration, and mental well-being, objectives that have become increasingly critical in post-pandemic urban contexts. As urban densities intensify, the challenges of designing resilient elevated spaces call for innovative approaches and strategic policies. This evolution is exemplified by cities like Singapore, which has implemented advanced planning directives to embed nature within high-rise environments and address both ecological and social imperatives.

2.2 Elevating nature: Singapore's endeavour in creating green streets in the sky

The concept of creating vertical communal and urban spaces within tall buildings has recently gained renewed interest in Singapore [4, 9]. As a densely populated and culturally diverse country, Singapore, like many other Asian cities, is experiencing a significant increase in the construction of tall buildings, leading to a greater concentration of life in the vertical realm [7, 24]. Singapore offers several precedents for tall buildings that foster socially sustainable vertical communities. The city has successfully transformed conventional repetitive high-rise housing blocks into innovative and ambitious urban hybrid spaces and communal areas that cater to the needs of both residents and the wider public [10, 11]. This trend reflects the evolving urban landscape and underscores the importance of integrating social sustainability into the planning and design of tall buildings, particularly in Singapore, where the high population density necessitates innovative solutions to meet residents' social and communal needs [7].

Singapore's public housing system is unique, serving not just low-income families but a broad socio-economic spectrum. The Housing and Development Board (HDB) provides flats at prices 20–30% lower than the private market, promoting social integration and preventing ethnic and economic segregation [7, 26]. New high-rise developments are designed to accommodate a mix of socio-economic backgrounds, fostering diverse communities [4].

The advancement of sky gardens has been significantly promoted by the HDB within high-rise social housing. Private enterprises are encouraged to incorporate such features through the Landscaping for Urban Spaces and High-rises (LUSH) planning directive. This initiative aligns with Singapore's ambition to become a 'Garden City' [24]. The LUSH policy mandates that developers integrate green spaces covering at least the total area of the site. To incentivise this, developers are

offered benefits such as exemptions from floor area tax and increased plot ratios for including sky gardens, landscaped rooftops, and alfresco areas [4, 27].

Singapore's progressive urban planning policies have led to numerous high-rise buildings featuring prominent sky gardens and extensive green spaces. These vertical green communal areas enhance visual appeal, foster community interactions, and mitigate the urban heat island effect [9, 10]. The widespread implementation of sky gardens is a result of strategic urban planning and regulatory initiatives, not happenstance.

The LUSH planning directive has been pivotal in promoting green spaces within Singapore's urban landscape, delivering environmental and social benefits. These green spaces help mitigate the urban heat island effect, reduce air pollution, and provide communal areas for leisure and social interactions [25, 28]. Additionally, the LUSH policy supports sustainable urban development by reducing the city's carbon footprint and energy consumption [4]. The success of the LUSH policy serves as a model for other cities aiming to enhance urban sustainability and residents' quality of life [7].

2.3 A morphological study of elevated urban spaces

In urban planning and architectural design, the morphology of built environments is crucial. It influences both the aesthetic character and the functionality of structures. As cities expand and densify, vertical solutions have become essential in urban design, leading to the development of various elevated urban spaces (Table 1). This section categorises these spaces into five main morphologies: Sky Gardens, Integrated Skywalks and Connected Sky Gardens, Courtscrapers, Rooftop Gardens, and Elevated Parks. Each category is examined for its unique form, functional narrative, and notable global examples, highlighting their potential in shaping future urban landscapes [5, 29].

The positioning and location of these spaces within tall mixed-use or hybrid buildings are vital. The placement of sky gardens and communal spaces presents significant challenges in terms of accessibility and vertical circulation [4, 5]. Achieving a balance between public accessibility and privacy is complex [12]. Many tall buildings place public or semi-public sky gardens at their summit, attracting visitors with panoramic city views. This not only serves as a city landmark but also generates revenue [10]. Conversely, private sky gardens for residents are typically located on the middle floors, with the building's form significantly influencing the placement and effectiveness of these spaces [4].

Buildings with tapering tops, such as 'The Shard', offer limited space for gardens and communal areas, necessitating a rethinking of spatial allocation strategies [5]. In contrast, structures with larger top floors, like '20 Fenchurch Street', provide opportunities for well-designed sky gardens [11]. The morphology of the ground levels of tall buildings is also important. Buildings constructed on a base or podium can create additional public roof gardens. Conversely, buildings elevated on substantial structures, such as Richard Rogers' '8 Chifley', free up ground level space for public use. Rogers pioneered raising the building to create accessible public spaces with direct visual access to various public functions and amenities [30].

Integrated skywalks and connected sky gardens represent another dimension of elevated urban spaces. This concept, widely adopted in Singapore, is attributed to Moshe Safdie, who has implemented it in several of his projects, including 'The Marina Bay Sands' and 'Sky Habitat' [11, 31]. These interconnected buildings establish a hierarchy of private and public sky gardens at various levels, fostering a vibrant vertical community [9].

The Courtscraper and pixelated towers are innovative typologies in the design of elevated urban spaces within hybrid buildings [14]. The Courtscraper combines high-density skyscrapers with communal courtyards characteristic of European residential architecture. This approach incorporates greenery and shared spaces in high-rise dwellings, aiming to humanise these structures and transform them into vertical urban forests [14]. This is achieved by adapting the concept of 'living in a house with a garden' to pixelated building blocks featuring private green courtyards, terraces, and roof gardens. Notable projects include VIA 57 West, Valley, Sky Habitat, and Bosco Verticale [29].

Rooftop gardens, a classic form of elevated urban space, provide versatile areas for various purposes, from recreational activities to food production [25]. They also play a crucial environmental role by offering green spaces that help offset the building's carbon footprint. The public roof gardens of London exemplify this trend, with many older buildings repurposing their rooftops into public gardens, often accompanied by bars. Libraries are also embracing this trend, with the Library of Birmingham's rooftop garden being a notable example [16].

Elevated parks represent the final form of elevated urban spaces. Typically built above ground level on man-made structures such as bridges and public transit stations, these parks offer a novel approach to urban green spaces [32]. They

Table 1 Morphological Study of Elevated Urban Spaces (Source: Author)

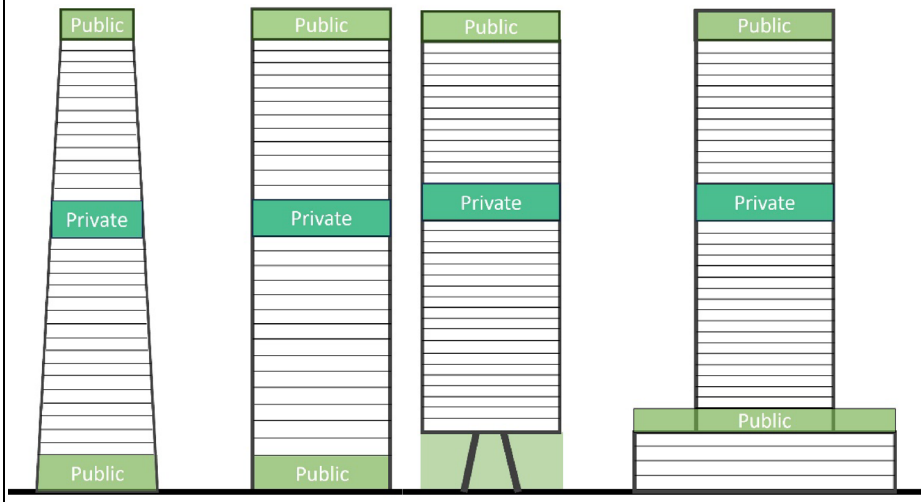
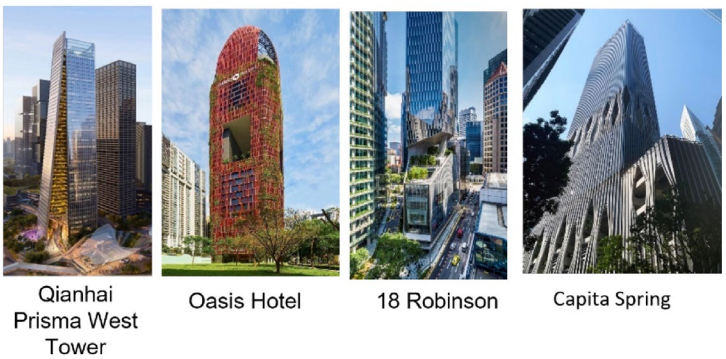
Elevated Urban Spaces	Form
Sky Gardens (Mixed-use Sky Scraper)	
	Examples
	 

Table 1 (continued)

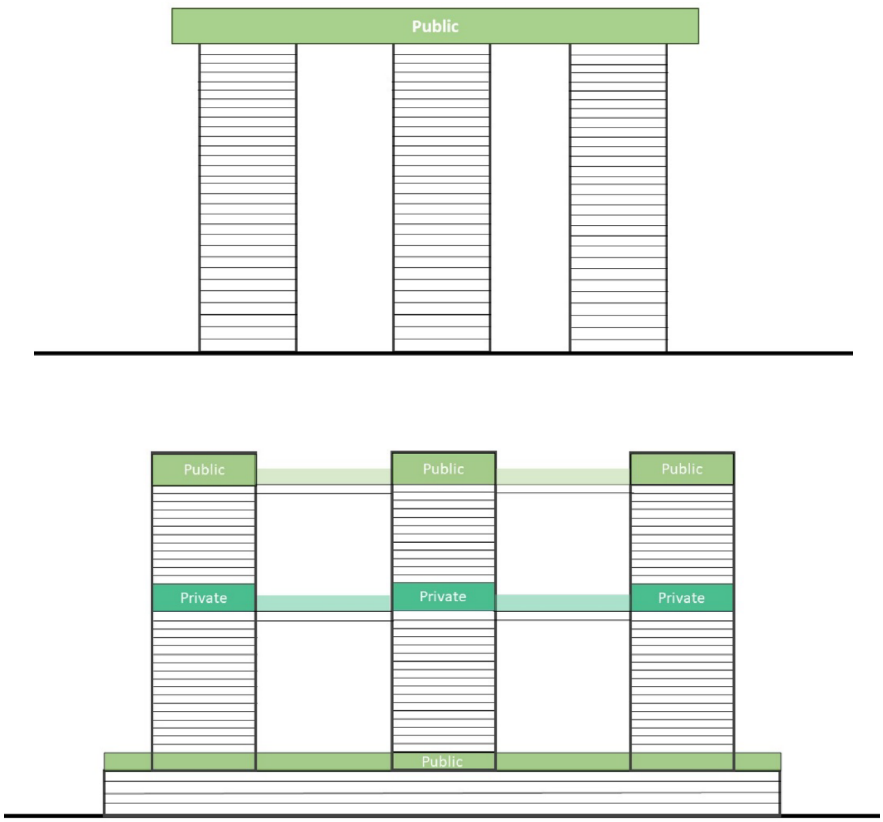
Sky Bridges & Connected Sky Gardens	
	Examples
	 Linked Hybrid  Orca  Marina Bay Sands  The Crystal

Table 1 (continued)

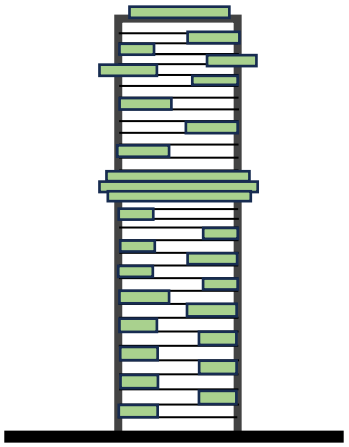
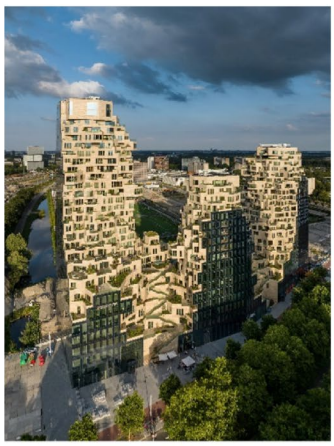
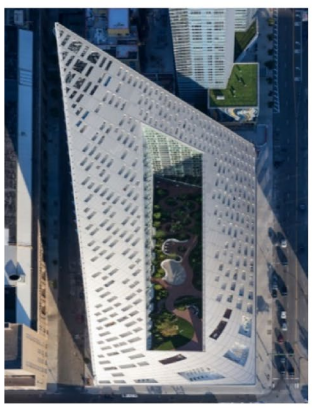
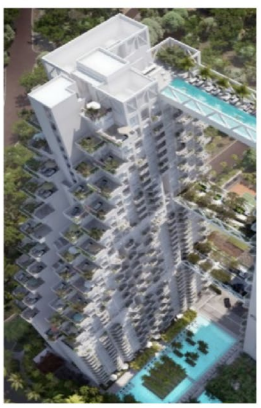
Court Scraper & Sky Courts	 
	Examples
	 Valley  QORNER Quito  Empire City Tower  VIA 57 West Apartments  Bosco Verticale  Sky Habitat

Table 1 (continued)

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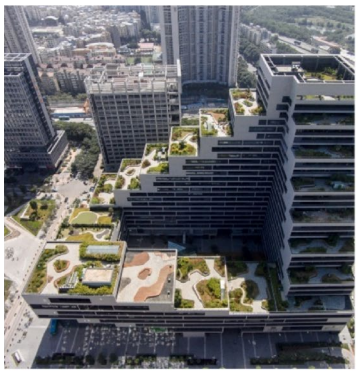
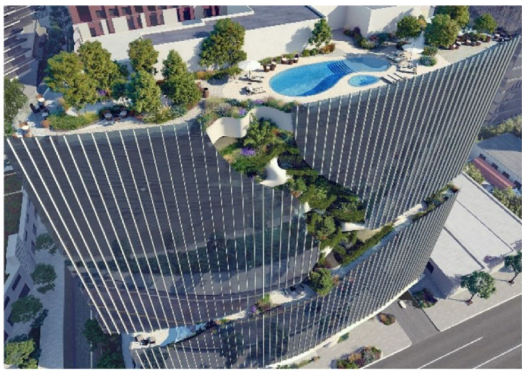
<tr><td></td><td> 
Shenye TaiRan
 
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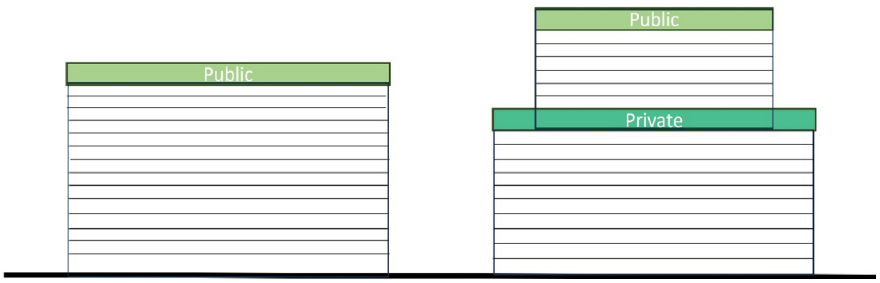
<tr><td rowspan="3">Roof Gardens</td><td>  </td></tr>
<tr><td>Examples</td></tr>
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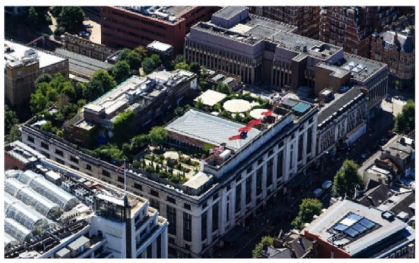
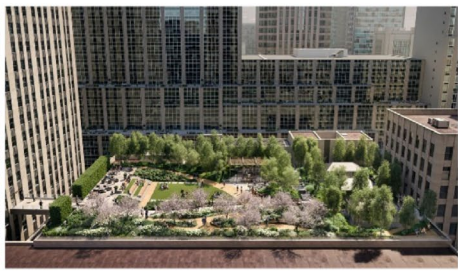
10 Fenchurch Avenue Building
 
Nieuwe Instituut
 
Kensington Roof Gardens
 
Radio City Musical Hall Rooftop Park</td></tr>
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Table 1 (continued)

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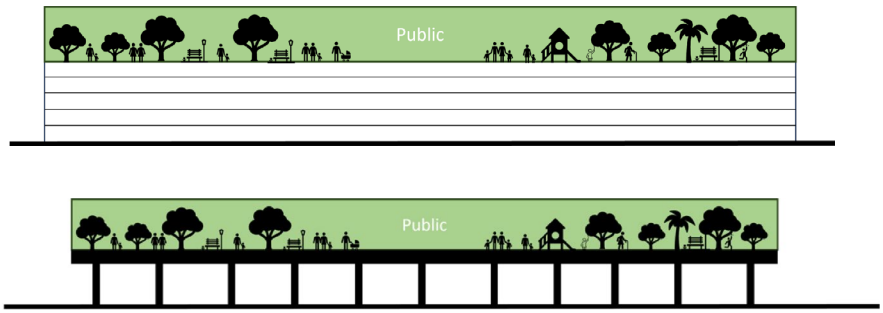
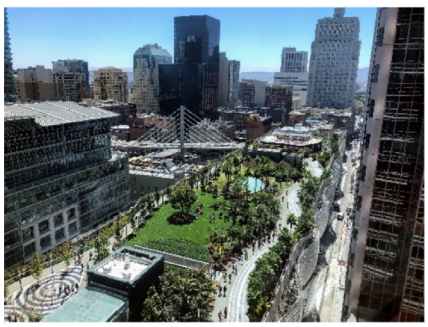
Birmingham Library Rooftop Garden</td></tr>
<tr><td rowspan="3">Elevated Parks</td><td>  </td></tr>
<tr><td>Examples</td></tr>
<tr><td> 
The High Line
 
Crossrail Place
 
Salesforce Park- Salesforce Transit Centre
 
Seoullo 7017</td></tr>
</table>

provide city dwellers with a respite from the urban hustle while also serving as pedestrian corridors, reducing street-level congestion [33]. Prominent examples like New York's High Line, Seoullo 7017 in Seoul, and Crossrail Place in London have transformed decommissioned infrastructure into vibrant urban habitats [32]. This repurposing of space addresses limited land resources and adds an additional layer to the cityscape. Consequently, elevated parks demonstrate the potential for integrating nature within the dense fabric of urban environments.

2.4 Biophilic design and elevated urban spaces: fostering resilience in high-density cities during pandemics

The COVID-19 pandemic underscored the crucial role of green spaces and biophilic design in promoting mental health in densely populated urban areas. Green spaces serve as vital refuges from the built environment, enhancing psychological well-being by fostering a connection to nature [34, 35]. The biophilia hypothesis, introduced by Wilson [36] and expanded by Kellert and Wilson [37], posits an inherent human affinity for nature, supporting the integration of natural elements in urban settings to improve mental health [38, 39]. During the pandemic, access to green spaces helped alleviate adverse psychological effects of lockdowns, such as anxiety and depression, highlighting their importance for urban resilience [40].

Historical and contemporary studies reveal the mental health benefits of green spaces. Urban parks, advocated by Frederick Law Olmsted in the nineteenth century, were essential for combating communicable diseases and improving societal well-being [41]. Recent research corroborates this, showing that proximity to green spaces correlates with better mental health outcomes [42]. In Auckland, New Zealand, closer access to green spaces was linked to reduced anxiety and mood disorders [43]. Similarly, European studies indicate that green spaces enhance vitality and mental health, irrespective of climatic and cultural factors [44, 45].

In high-density cities, where ground-level green spaces are scarce, alternative typologies like roof gardens, sky courts, and elevated parks offer innovative solutions. These elevated green spaces foster biophilic connections, support social distancing, reduce crowding, and mitigate viral transmission risks [46, 47]. They also enhance urban biodiversity, improve air quality, and address climate change, contributing to overall human and environmental health [7, 48]. The 2020 lockdowns in countries like Spain, Italy, and France showcased the potential of balcony spaces for social engagement, highlighting the importance of these micro-spaces for mental well-being [49, 50].

Biophilic design principles play a central role in this study's framework by promoting resilience and enhancing urban quality of life. Integrating natural elements such as greenery, natural light, and water into elevated spaces directly supports environmental sustainability by mitigating urban heat and improving air quality, while simultaneously fostering mental and social well-being. This approach aligns with the study's goal of creating resilient urban spaces that adapt to the unique demands of hyper-dense environments. The framework outlined in this study draws on these biophilic principles, positioning them as essential components for sustainable and inclusive design in modern urban settings.

To maximise their benefits, urban planners and policymakers must develop comprehensive design guidelines ensuring accessibility, safety, and inclusivity [51, 52]. Elevated green spaces' sustainability faced challenges during the pandemic, such as temporary closures to protect health and safety [53, 54]. Future research should focus on creating effective design models and best practices for resilient and sustainable elevated urban spaces, enhancing our understanding of human behaviour and interactions within these areas [5, 55].

2.5 Elevated urban spaces in London: successes and challenges

The emergence of elevated urban spaces in London has introduced a novel category of public space, attracting considerable scholarly interest. These spaces offer unique opportunities to incorporate nature, light, and greenery into densely populated urban areas, providing sanctuaries from the city's frenetic pace (Table 2). However, their development necessitates addressing numerous challenges to ensure their long-term viability and success.

Since the inauguration of the world's first underground railway in 1863, London has evolved into a multi-layered city [56, 57]. In the twenty-first century, it has transformed into a 'skyscraper city,' with numerous towers exceeding 100 m, some featuring elevated urban spaces [12, 58]. Notable projects such as the Sky Garden at 20 Fenchurch Street, The Garden at 120 Fenchurch Street, and Crossrail Place at Canary Wharf exemplify this innovative concept. These spaces, now integral to the city's public space portfolio, are central to debates about their potential as vibrant

Table 2 Elevated urban spaces in London (Source: Author)

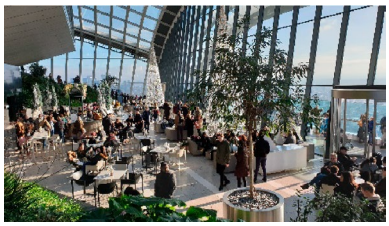
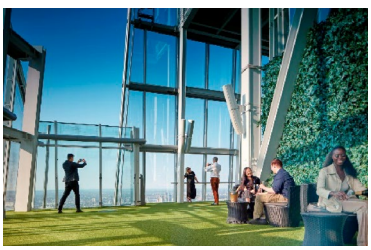
Name	Type and Functions	Building Name and Functions	Access and Location	Privacy and Accessibility	Image
Sky Garden	Sky Garden	20 Fenchurch Street (The Walkie-Talkie)	Floor: 35-37, 20 Fenchurch Street,	Accessible with free entry ticket (pre-booking required)	
	Viewing platform, restaurant, bar, event space, garden	Office, Mixed-Use	Lifts	Security gates check in required	
The Shard Sky Deck	Sky Deck	The Shard	Floor: 72, The Shard, 32 London Bridge St, London	accessible with entry fee (booking required)	
	Viewing platform, events	Mixed use (Office, hotel, restaurants, Viewing deck)	Lifts	Security gates check in required	 

Table 2 (continued)

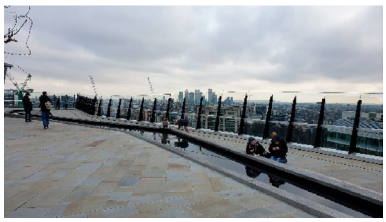
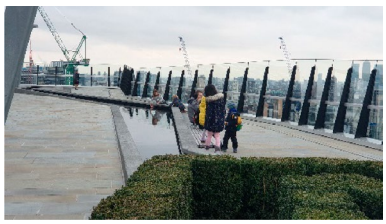
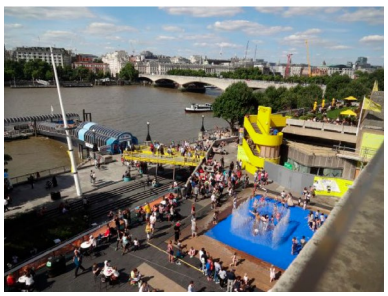
The Garden at 120	Roof Garden	One Fen Court	Floor: 15, One Fen Court, 120 Fenchurch Street	Accessible with free entry (no booking required)	
	Viewing platform, garden, seating area	Mixed use (office and retail)	Lifts	Security gates check in required	 
The Roof Terrace at Queen Elizabeth Hall	Roof Garden	Queen Elizabeth Hall	Floor: 3, Queen Elizabeth Hall Southbank Centre	Accessible with free entry (no booking required)	
	Garden, seating area, outdoor bar	Cultural, Performing Arts Venue	Lifts and stairs	No security gates	 

Table 2 (continued)

Crossrail Place Roof Garden	Elevated pocket park	Crossrail Place	Floor: 4, Crossrail Place, Canary Wharf	Accessible with free entry (no booking required)	
	Garden, seating area, event space, amphitheatre, bar and restaurants	Mixed-Use (Retail, Office, Canary Wharf rail way station)	Lifts and escalators	No security gates	 
Barbican Beech Gardens	Elevated park	Barbican Estate	High Walk level, Barbican Estate, Barbican	Accessible with free entry (no booking required)	
	Garden, seating area, walkways	Mixed-Use (residential, cultural)	Lifts and stairs	No security gates	 

Table 2 (continued)

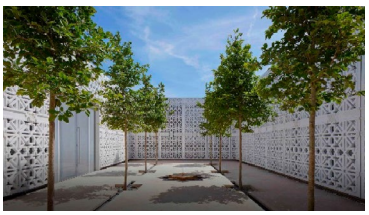
Aga Khan Islamic Gardens	Roof Garden and interconnected Terraces	Aga Khan Centre	Floors: 3, 4, and 7, Aga Khan Centre, 10 Handyside Street	Accessible with free entry (no booking required)	
	Garden, Islamic cultural experience, event space	Cultural Institution	Lifts	No security gates	 
The Roof Park	Roof Garden	Bootstrap Building	Floor: 2, Bootstrap Building, Dalston	Accessible with free entry (no booking required)	 
	Garden, seating area, event space, workspace	Mixed use (community and workspace areas)	Lifts and stairs	No security gates	

Table 2 (continued)

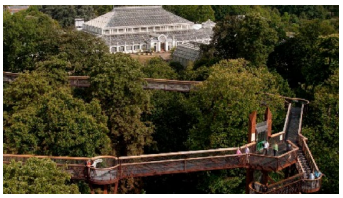
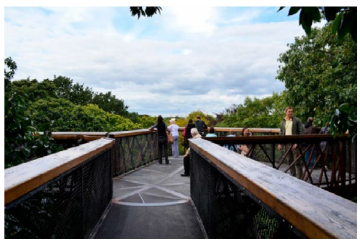
John Lewis Roof Garden	Roof Garden	John Lewis & Partners Oxford Street	Floor: 5, John Lewis & Partners, Oxford Street,	Accessible with free entry (no booking required)	
	Garden, seating area, seasonal events	Retail	Lifts and escalators	No security gates	 
Kew Gardens Aerial Walkway	Elevated Walkway	Kew Gardens	Kew Gardens, Richmond	Accessible with garden entry fee (no booking required)	
	Walkway, tree canopy exploration, nature experience	Royal Botanic Gardens	Stairs	No security gates	 

Table 2 (continued)

Coutts Skyline Garden	Roof Garden	Coutts Bank Building	Floor: 6, Coutts Bank Building, 440 Strand	Private, accessible for Coutts employees and clients only,	
	Garden, event space, sustainable showcase	Mixed use (Bank, office building and roof garden)	Private lift, which requires an access card to operate	Security gates	 

and inclusive urban areas [9, 31]. Despite their initial public accessibility, the COVID-19 pandemic significantly impacted their operations, leading to closures or modifications to comply with health regulations.

The future of elevated urban spaces is a topic of considerable debate among scholars. Proponents argue that these spaces can foster functional, sustainable urban environments, accommodating diverse and dynamic urban conditions, particularly during pandemics. They advocate for reimagining public spaces in a three-dimensional context, suggesting that vertical public realms, such as roof gardens and elevated parks, could reduce travel distances and enhance the concept of 15-min neighbourhoods in high-density cities like London. Conversely, critics highlight the limitations and challenges that require further study, including accessibility, circulation, design, security, safety, and management. Addressing these issues demands innovative, interactive design frameworks to develop resilient elevated urban spaces effectively.

3 Methodology

3.1 Case studies

This research examined two prominent examples of elevated public spaces in London: the Sky Garden on the upper floors of the Walkie Talkie building and the Crossrail Place Roof Garden at Canary Wharf. The selection of Sky Garden and Crossrail Place Roof Garden as case studies is particularly pertinent to this research due to their unique status as well-publicised, open-access elevated spaces within London's high-density urban setting. Both sites exemplify distinct prototypes of elevated public spaces, each demonstrating different approaches to location, accessibility, and design that aligns closely with the study's objectives of exploring urban resilience and inclusivity. These spaces were chosen following an extensive literature review, as they offer free public access and attract a diverse range of visitors, allowing for a comprehensive analysis of user interactions and spatial dynamics. The challenges these sites faced during the COVID-19 pandemic further provided an opportunity to

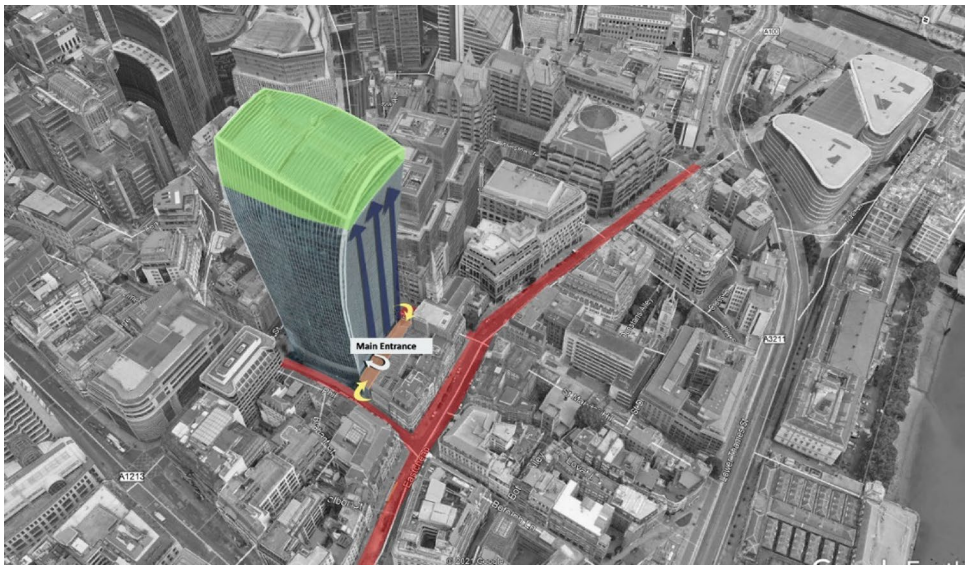


Fig. 1 Sky Garden accessibility from the street level. Source: Author

Fig. 2 3D plan illustrating the layout of various activities and functional zones within the Sky Garden, showcasing spaces designed for relaxation, social interaction, and visitor engagement. Source: Author

examine how elevated spaces adapt to health and safety regulations, offering critical insights into sustainable and resilient design strategies in dense urban environments.

The study sought to compare and analyse these spaces, focusing on elements such as user access, spatial dynamics, activities, security, management, and health and safety protocols. It investigated user interactions, identified design issues, and evaluated how adaptations to COVID-19 regulations influenced user behaviour. The insights derived from these case studies were utilised to develop a user-centric framework and guidelines for the design of elevated urban spaces. This approach ensures that the design process is inclusive and responsive to the needs and experiences of end-users, ultimately enhancing the functionality and sustainability of these urban spaces.

3.2 Sky garden

This study examines the Sky Garden at 20 Fenchurch Street, a unique vertical social space in London. Chosen for its distinctive architecture, prime location, and free-entry policy, the Sky Garden remained operational whenever legally feasible throughout the COVID-19 pandemic. Located on the top three floors of the 'Walkie Talkie' skyscraper in London's financial district, the Sky Garden spans levels 35–37, with a dedicated entrance on Philpot Lane [12, 59] (Figs. 1 and 2).

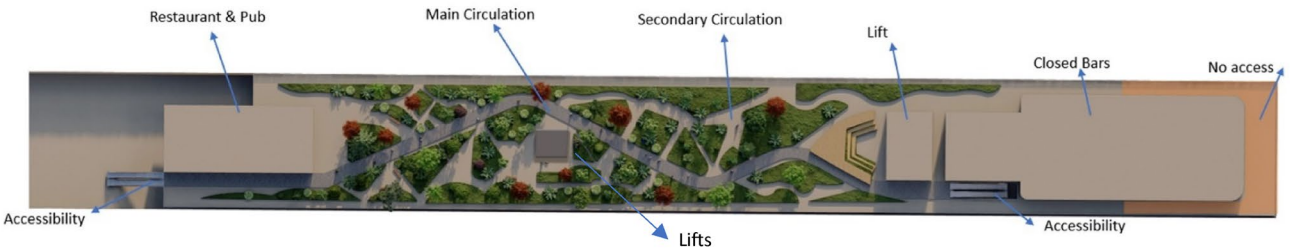


Fig. 3 Crossrail Place Roof Garden Layout, Canary Wharf, London. Source: Author's Digital Model

Fig. 4 Crossrail Place Roof Garden, located in Canary Wharf, London, demonstrating an elevated green space designed to encourage relaxation, social interaction, and connection with nature within an urban environment. Source: Author

Visitors undergo stringent security checks before ascending to Level 35 via the lift. Tickets are booked online three weeks in advance, but entry is not guaranteed if capacity is reached. Those exceeding a one-hour stay may be asked to leave, with re-entry requiring special permission and repeated security checks [12, 60].

The pandemic significantly affected the Sky Garden's operations, reducing visitor capacity from 600 to 200, and limiting lift use to six guests from the same household. The garden had to close temporarily during the 2020 lockdowns, posing challenges in maintaining ventilation and indoor air quality. Upon reopening, effective ventilation and air filtration systems were crucial. The Sky Garden employs a mix of natural and mechanical ventilation, using vents, louvers, air handling, and heat recovery units, along with advanced air filtration to ensure a clean and healthy environment [60, 61].

3.3 Crossrail place roof garden

The second case study focuses on the Crossrail Place Roof Garden in Canary Wharf, selected for its distinctive features in location, accessibility, and design. Spanning approximately 10,000 square metres, this elevated, covered park is situated above the Elizabeth Line's subterranean route. The park's flora and layout reflect the geography and history of Canary Wharf [62]. The Canary Wharf Group aimed to create a community park usable year-round, addressing the scarcity of green spaces in the London Docklands area [63] (Figs. 3 and 4).

Visitors access the roof garden via escalators or public lifts from street level. The garden is sheltered by a sophisticated timber lattice roof with ETFE vaults, promoting daylight and natural irrigation. The park includes a pub, a restaurant, and an amphitheatre, and is open to the public from 09:00 to 21:00 without the need for pre-booking. Managed to the same high standards as the rest of the Canary Wharf estate, the security plan, approved by the London Borough of Tower Hamlets, aims to "curb crime and the perception of crime," prohibits smoking and alcohol consumption (except within the pub), and adjusts closing times to midnight due to the popularity of the pub and restaurant. The park is under extensive CCTV surveillance, with footage monitored and stored for a set period [62].

3.4 Semi-structured walk-along interviews

The study sought to examine the relationship between visitors' behaviour and the design of vertical urban spaces through semi-structured walk-along interviews. This method explored the cognitive and physical experiences of space users, focusing on factors that facilitate social interactions within these environments [63]. The interviews

were conducted within a phenomenological qualitative framework, which aims to understand the lived experiences of participants and uncover the essence of a particular phenomenon [64, 65]. The phenomenological approach seeks to explore and interpret individuals' personal experiences and the meanings they ascribe to them. Rooted in phenomenology, this approach emphasises examining the essence of a phenomenon as perceived by individuals, revealing the complexities and nuances of their subjective realities [64, 65].

This approach is particularly suited to studies seeking deeper insights into human emotions, beliefs, and perceptions that may not be easily quantified or generalised [66]. In the context of this study, the phenomenological framework enabled a detailed analysis of participants' experiences within elevated urban spaces. It captured their unique perceptions of spatial design and social interaction. Such insights are often difficult to obtain through quantitative or other qualitative methods [67]. This emphasis on lived experiences and subjective interpretations allows researchers to explore the complex relationships between people and their built environments, leading to valuable insights and knowledge in the field. This approach is invaluable for investigating complex phenomena that resist quantification, as it enables researchers to capture the depth and richness of human experiences, thereby uncovering insights that other methods may not reveal [66, 67].

While we acknowledge the advantages of triangulating data through additional methods like observational studies, our focus remained on walk-along interviews due to their unique capacity to capture real-time experiences. This method is highly effective in co-design processes, as it enables researchers to observe participants' interactions with the space while simultaneously gathering feedback that informs design improvements. Walk-along interviews are particularly useful for understanding the interplay between physical design elements and user behaviour in dynamic urban environments, making them a valuable tool for this study. Prior research has demonstrated the effectiveness of this method in studying urban public spaces and park use [63, 66]. We have addressed this methodological focus in the manuscript to ensure transparency.

Walk-along interviews were conducted with a diverse group of participants aged 18 and older. Engaging in open-ended conversations, the researcher encouraged participants to share their impressions, feelings, and opinions about the space, thereby collecting rich, context-specific data that traditional interviews might miss [68]. A total of thirty-three interviews were conducted at each location, each lasting approximately 30 min (Fig. 5). Participants were recruited on-site and provided with study details, the expected duration of their involvement, and an ethics consent form. The information gathered offered deep insights into participants' experiences, enhancing the understanding of factors influencing social interactions within elevated urban spaces.

The author employed a theme-based analysis using various qualitative data sets. Data were analysed using content analysis, guided by a summative approach [69, 70]. This process involved creating themes derived from literature and theoretical concepts, breaking down interviews into data chunks, coding these chunks, and analysing the relationships between themes and sub-themes. The final stage involved constructing a narrative from the themes and codes, describing the themes, and supporting these descriptions with quotes from the interviews. This comprehensive analysis aimed to uncover the relationships between overarching themes and identify initially hard-to-classify quotes, ensuring a thorough understanding of the data.

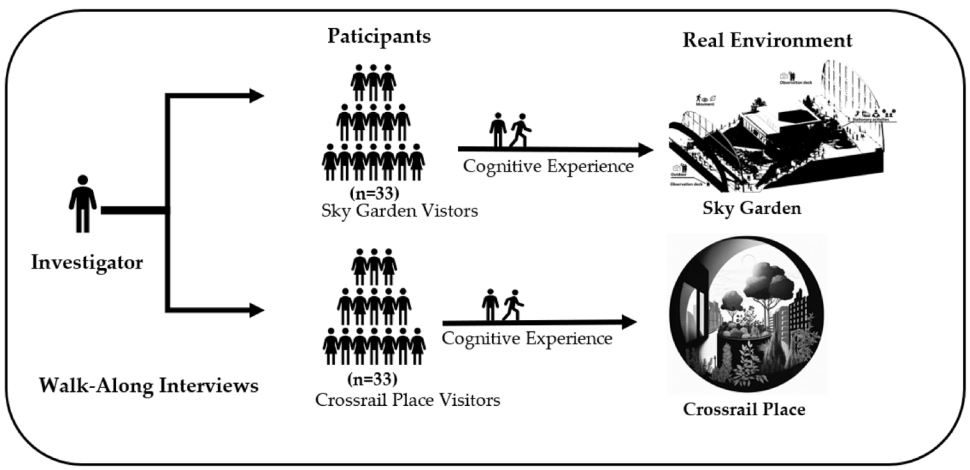


Fig. 5 Methodological framework demonstrates the methods used in the walk-along interview. Source: Author

Table 3 Demographic characteristics of participants at Sky Garden and Crossrail Place (Source: Author)

Demographic information	Sky Garden	Crossrail Place
Interviews number	33	33
Gender		
Male	39.3% (n = 13)	45.4% (n = 15)
Female	60.6% (n = 20)	54.5% (n = 18)
Average age (years)	28.2	30.3
Residency/Work		
Living/Working in London	36.6% (n = 12)	60.6% (n = 20)
Living Elsewhere in the UK	39.4% (n = 13)	24.2% (n = 8)
International Tourists	24.2% (n = 8)	15.1% (n = 5)

3.5 Qualitative data analysis

A total of 66 interviews were conducted across both gardens. Of these, 33 were carried out at the Sky Garden in November 2021, with a gender distribution of 39.3% (n = 13) male and 60.6% (n = 20) female. The average age of the participants was 28.2 years. Regarding residency, approximately 36.6% (n = 12) of the respondents lived in London, 39.4% (n = 13) in other parts of the UK, and 24.2% (n = 8) were international tourists visiting London. In comparison, 33 interviews were completed at Crossrail Place in December 2021 (Fig. 5). The gender distribution there consisted of 45.4% (n = 15) males and 54.5% (n = 18) females. The average age of these participants was 30.3 years. Concerning their place of residence or work, approximately 60.6% (n = 20) of the interviewees lived or worked in Canary Wharf, 24.2% (n = 8) resided in other parts of London, and 15.1% (n = 5) were short-term visitors to London, primarily tourists (Table 3).

3.6 Interview guide and coding process

The semi-structured interviews employed in this research were carefully designed to elicit rich, qualitative data from participants regarding their experiences with elevated urban spaces. The interview questions were strategically developed to align with the primary research objectives, aiming to explore participants' interactions with and perceptions of urban environments. Specifically, the questions sought to uncover insights into how design elements, accessibility, and the emotional resonance of these spaces influence user experience. Key themes that underpinned the interview guide included accessibility and ease of navigation, emotional and psychological responses to urban spaces, and the impact of architectural features on the engagement with these environments.

To illustrate, participants were asked about their frequency of visits to elevated urban spaces, the activities they typically engaged in, and how design elements affected their experience. Additionally, the interviews probed whether the COVID-19 pandemic had altered participants' use of such spaces, allowing for a dynamic exploration of the evolving interaction between individuals and urban environments. The semi-structured format permitted flexibility, enabling participants to offer deeper reflections that extended beyond the predefined questions, thus enriching the dataset.

The qualitative data collected from the interviews were analysed through a rigorous coding process following an inductive thematic approach. Initially, all interview transcripts were thoroughly reviewed to ensure familiarisation with the content. This preliminary step allowed for the identification of recurring patterns and notable insights. Subsequently, initial codes were generated using NVivo software, with segments of the text being assigned descriptive labels such as "challenges in accessibility" and "emotional responses to space." The coding was an iterative process, involving repeated engagement with the data to ensure the accuracy and relevance of the codes.

As the analysis progressed, these initial codes were grouped into broader themes that reflected the key research questions. For instance, codes related to safety and a sense of belonging were consolidated under the broader theme of "emotional responses to urban spaces." This thematic analysis was not merely descriptive but also interpretative, seeking to uncover the deeper meanings embedded within the data. The final phase of the coding process involved refining the themes, ensuring that they captured the complexity and nuance of the participants' experiences while remaining grounded in the research objectives.

To enhance the reliability of the coding process, multiple coders were involved in the analysis. Each coder independently reviewed a subset of the transcripts, and discrepancies in coding were resolved through detailed discussions, thus

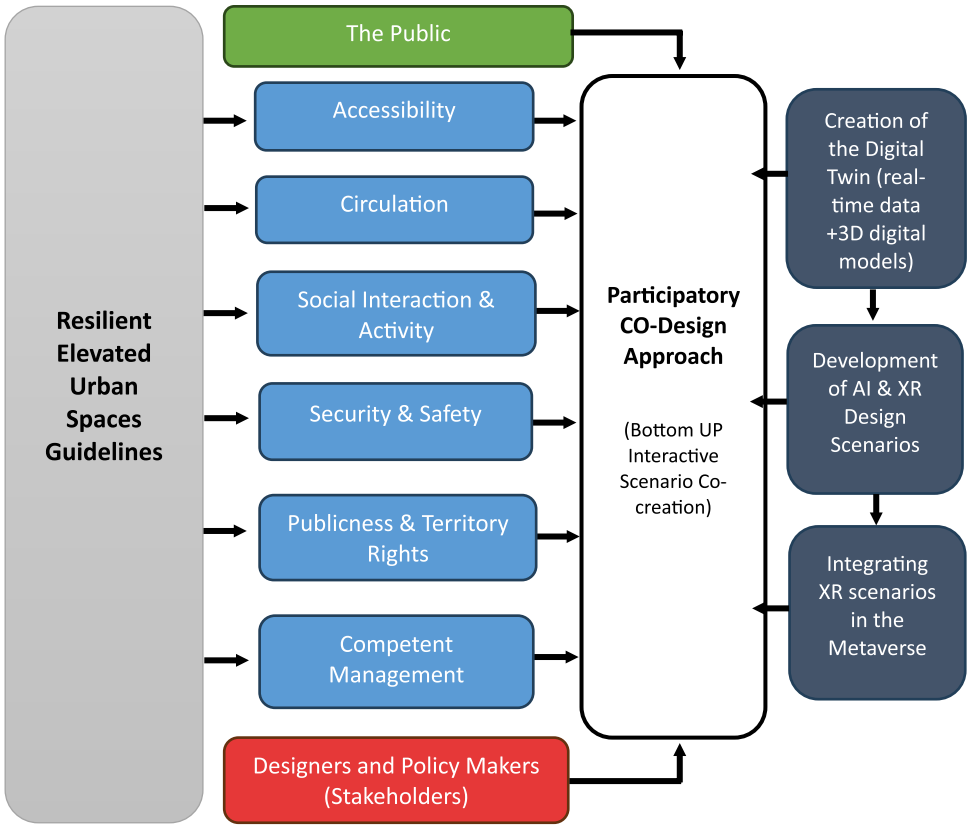


Fig. 6 Framework of Resilient Elevated Urban Spaces, outlining key principles and guidelines for designing adaptable, inclusive, and sustainable urban green spaces in high-density areas. Source: Author

ensuring inter-coder reliability. This collaborative approach to coding not only increased the credibility of the analysis but also provided a robust framework for interpreting the data.

4 Results & framework

This research examines the multifaceted design challenges and guiding principles inherent in planning resilient elevated urban spaces. The dual case studies highlight numerous areas for potential enhancement, encompassing accessibility, circulation, aesthetic appeal, and management strategies. The study's results align with previous research on design problems and principles for vertical urban spaces [4, 5, 10]. Seven critical attributes were identified as essential components of an ideal elevated urban environment or rooftop garden: accessibility, efficient circulation, opportunities for social interaction and activity, a sense of security and safety, defined publicness and territorial rights, competent management, and a participatory co-design approach (Fig. 6).

4.1 Accessibility

Urban space resilience, from a functionality perspective, hinges on pedestrian accessibility [71, 72]. This study, supported by observational evidence and participant interviews, affirms this assertion. Accessibility includes universal reachability, unhampered by constraints [73]. A nuanced approach to pedestrian access fosters logical motion patterns and promotes desired behaviours, enhancing inclusivity [74, 75]. Carr et al. conceptualised three physical access forms: visual, physical, and symbolic [76]. Visual access previews the space, physical access regulates entry, and symbolic access infers safety and hospitality through spatial indicators [77, 78].

Application of these principles to Sky Garden and Crossrail Place reveals unique intricacies related to accessibility (Fig. 7). The Sky Garden, while presenting itself as a publicly accessible space, encounters significant challenges concerning both physical and visual accessibility, which in turn affects perceptions of its public nature. One of the primary obstacles is the requirement for visitors to pre-book a time slot at least two weeks in advance, which restricts spontaneous or

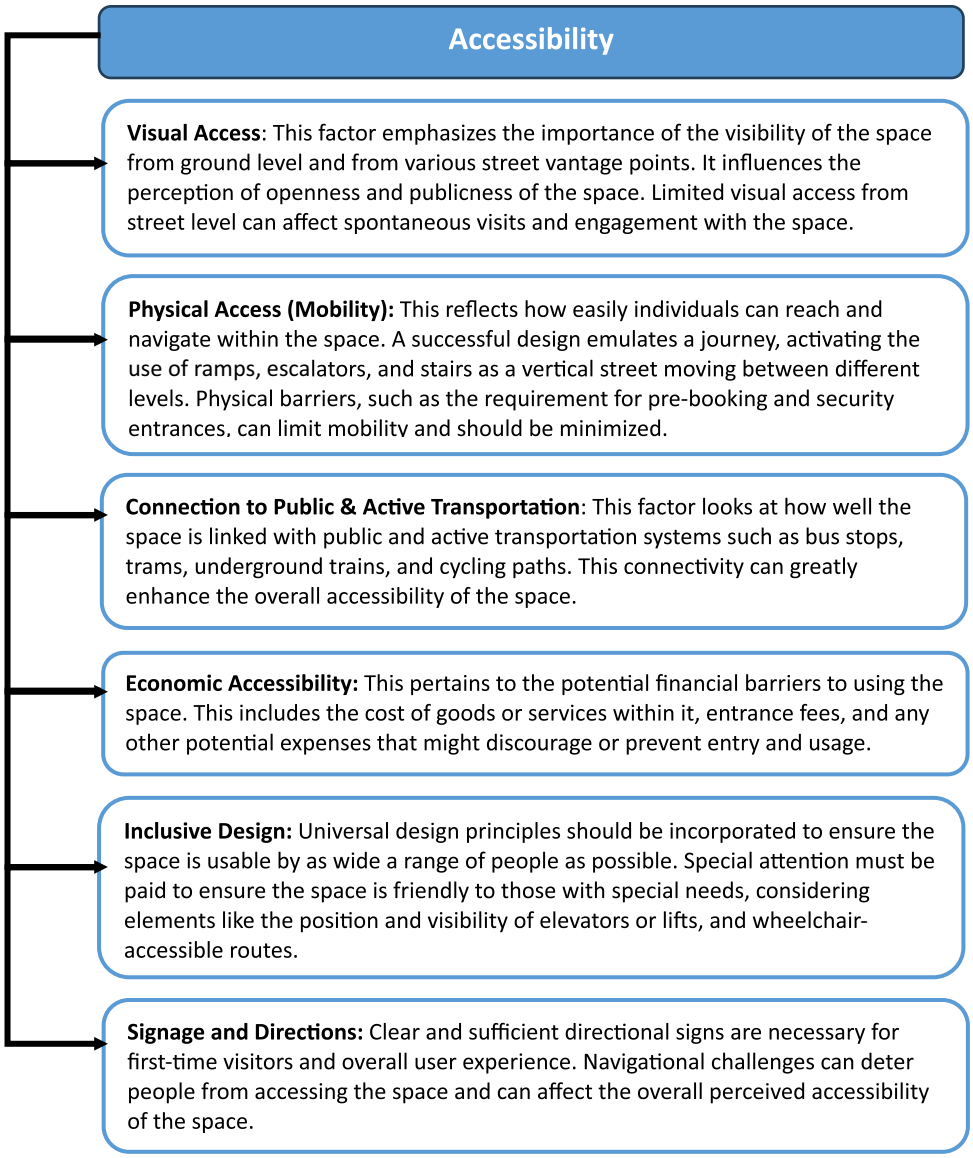


Fig. 7 Conceptual Framework Illustrating the Principal Aspects of Accessibility for Resilient Elevated Urban spaces. Source: Author

unplanned access. Additionally, its elevated position atop the 'Walkie Talkie' building inherently limits visual accessibility from street level, reducing the perceived openness and public character of the space.

The accessibility challenges were exacerbated by the Covid-19 pandemic. Enforced social distancing measures reduced the number of visitors allowed and constrained the capacity of lifts. Furthermore, the increased demand for natural ventilation, driven by the pandemic, posed additional difficulties, given the garden's reliance on artificial climate control systems due to its high-rise location. This crisis underscored the susceptibility of such elevated spaces to global disruptions, reinforcing the necessity for flexible and resilient design solutions.

In contrast, at Crossrail Place, the primary challenge in terms of accessibility arose from the limited visibility of the roof garden from ground level. This issue was particularly noticeable among first-time visitors, who often found navigating to the garden without clear signage or digital maps confusing. Although the garden was accessible via an escalator, the overall layout was considered perplexing, and visibility was widely regarded as insufficient. While the accessibility was enhanced by public transport options, including the Elizabeth Line, the Jubilee Line, and local bus services, the provision for individuals with special needs received mixed feedback. Although the garden was technically wheelchair-accessible, the positioning of the lift and the obstructed views from it were subject to criticism.

To improve the attractiveness and functionality of such elevated spaces, it is recommended to adopt a multi-modal transportation strategy, create a direct connection from street level to the roof garden, and incorporate symbolic features such as visible greenery from street level to signal its presence [11, 12, 20]. Furthermore, special needs accessibility must

be a priority in the design process to ensure inclusivity. Ultimately, for these spaces to fulfil their purpose, visitors must be able to access them easily and feel comfortable navigating within them.

Inclusive accessibility within elevated urban spaces is not simply a supplementary design consideration but a fundamental pillar of their functionality and success. Ensuring comprehensive, intuitive access is paramount to enhancing the public utility and social significance of these spaces, enabling a diverse spectrum of users to engage fully with them. Such inclusivity fosters a sense of community ownership, promotes social interaction, and enriches the vibrancy of the urban environment.

This study has illuminated both the challenges and opportunities inherent in designing these spaces, highlighting the need for careful, context-specific strategies. Each case study examined reveals distinct contextual parameters that demand bespoke solutions, demonstrating that a uniform, one-size-fits-all approach is insufficient. Instead, design interventions must be sensitively adapted to the unique characteristics and needs of the urban landscape in which they are situated.

Furthermore, the findings underscore the evolving nature of accessibility, influenced by societal changes and external factors such as the Covid-19 pandemic. It is imperative that urban planners and designers adopt a forward-thinking, flexible approach, remaining responsive to such shifts to ensure these spaces remain accessible and inviting in the face of unforeseen challenges. As such, future research must continue to probe this multifaceted issue, with an emphasis on developing innovative, resilient strategies that enhance accessibility and maintain the relevance of these spaces within an ever-changing urban context.

The limitations imposed by booking systems and restricted accessibility present significant implications for inclusiveness within elevated urban spaces. The pre-booking requirement, though effective for managing capacity, restricts spontaneous visits, which can inadvertently exclude certain user groups, such as individuals without online access or those less likely to plan visits in advance. This limitation not only reduces the potential diversity of users but may also hinder the space's role as an inclusive urban resource accessible to all demographics. Consequently, such barriers highlight the need for design strategies that balance access control with inclusive, flexible accessibility measures, ensuring that elevated spaces serve as equitable environments that support spontaneous public engagement and cater to a broader user base.

4.2 Circulation

Both the Crossrail Place and Sky Garden case studies offer substantial insights into circulation within elevated urban spaces, contributing significantly to the growing body of literature on urban design principles. The analysis of these spaces reveals both similarities and differences in how circulation is approached, highlighting key factors that influence user experience and engagement.

At Crossrail Place, the primary feature influencing circulation is the curved pathways, which actively encourage exploration and discovery. This design aligns with Kaplan's concept of 'mystery,' where people are drawn to environments that invite further exploration by not immediately revealing all their elements [79]. Participants praised the natural flow and organic layout of the space, emphasising how the garden's design facilitates a sense of immersion. One participant noted, "The winding paths make you want to keep walking, to see what's around the next corner," highlighting how the design inspires curiosity and social interactions as visitors linger and explore together. However, the narrowness of the pathways was raised as a concern, particularly for larger groups or those seeking privacy. This suggests that while curved pathways enhance exploration, broader walkways and designated private spaces are necessary to meet diverse user needs and improve comfort within elevated gardens. Another visitor remarked, "It feels a bit cramped when there are too many people, which makes it hard to find a quiet spot."

In contrast, the Sky Garden presents a more complex circulation system, particularly due to the significant impact of the COVID-19 pandemic on its spatial configuration. To ensure public safety, the garden's management implemented a one-way system, marked with clear social distancing indicators. While effective in reducing crowding, this system restricted the freedom of movement, in contrast to Whyte's principles of open access and unrestricted circulation, which are typically central to successful public space design. As one visitor mentioned, "The one-way system made it harder to move around freely and meet up with friends," underscoring how circulation constraints can limit spontaneous social interactions. Nevertheless, the necessity of this approach during the pandemic forced a rethinking of sightlines and wayfinding to maintain safe yet accessible routes for visitors, emphasising visibility and clear navigation throughout the space [5, 80]. Such changes underscore the importance of adaptability in design, particularly in response to unforeseen global events.

The pandemic also intensified the use of outdoor spaces for stationary activities, as people sought safe environments for relaxation and social interaction. This shift is in line with Oldenburg's 'third place' theory, which highlights the

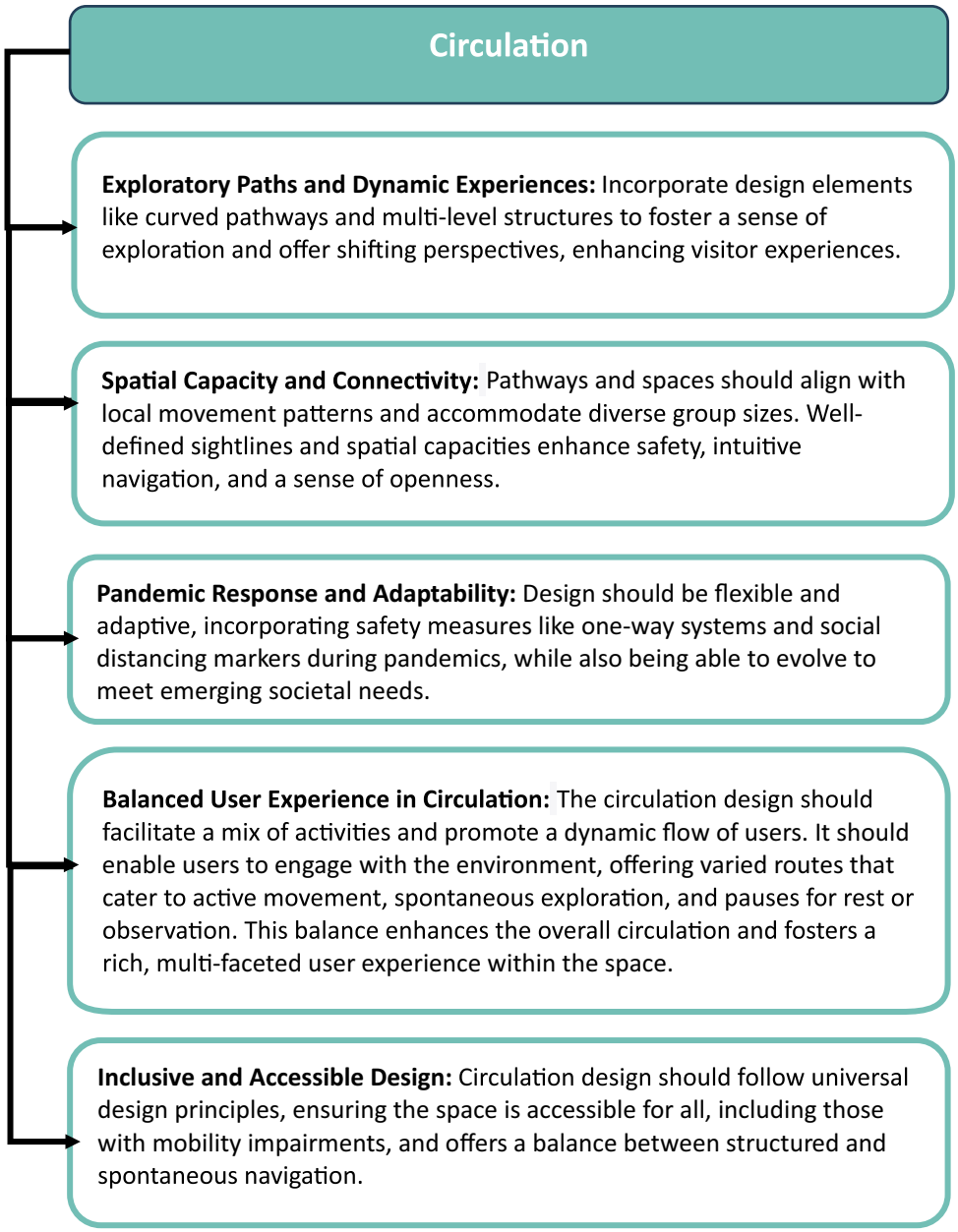


Fig. 8 Conceptual Flow Chart Illustrating the Principal Aspects of Circulation for Resilient Elevated Urban spaces. Source: Author

importance of public spaces as informal gathering places that encourage casual interactions [81]. At the Sky Garden, the introduction of amenities such as chaise lounges further fostered leisure activities, illustrating the capacity of elevated spaces to evolve and meet the changing needs of users, even in challenging circumstances [82, 83]. However, the garden's multi-level design, while dynamic and visually engaging, presented accessibility challenges for some, particularly individuals with mobility impairments. One visitor explained, "It's beautiful but difficult to navigate if you can't take the stairs," reinforcing the necessity of applying universal design principles to ensure that elevated spaces are accessible to all visitors, regardless of physical ability [84].

Both case studies highlight the need for careful consideration of exploration, accessibility, privacy, and safety when designing elevated urban spaces. Crossrail Place, with its natural layout and exploratory pathways, demonstrates the potential for elevated spaces to foster engagement with the environment, while the Sky Garden's experience during the pandemic illustrates the challenges of maintaining flexibility and accessibility in the face of unforeseen circumstances. Future designs must strive to balance these elements, ensuring that elevated urban environments remain vibrant, inclusive, and adaptable to the evolving needs of the public [5, 10].

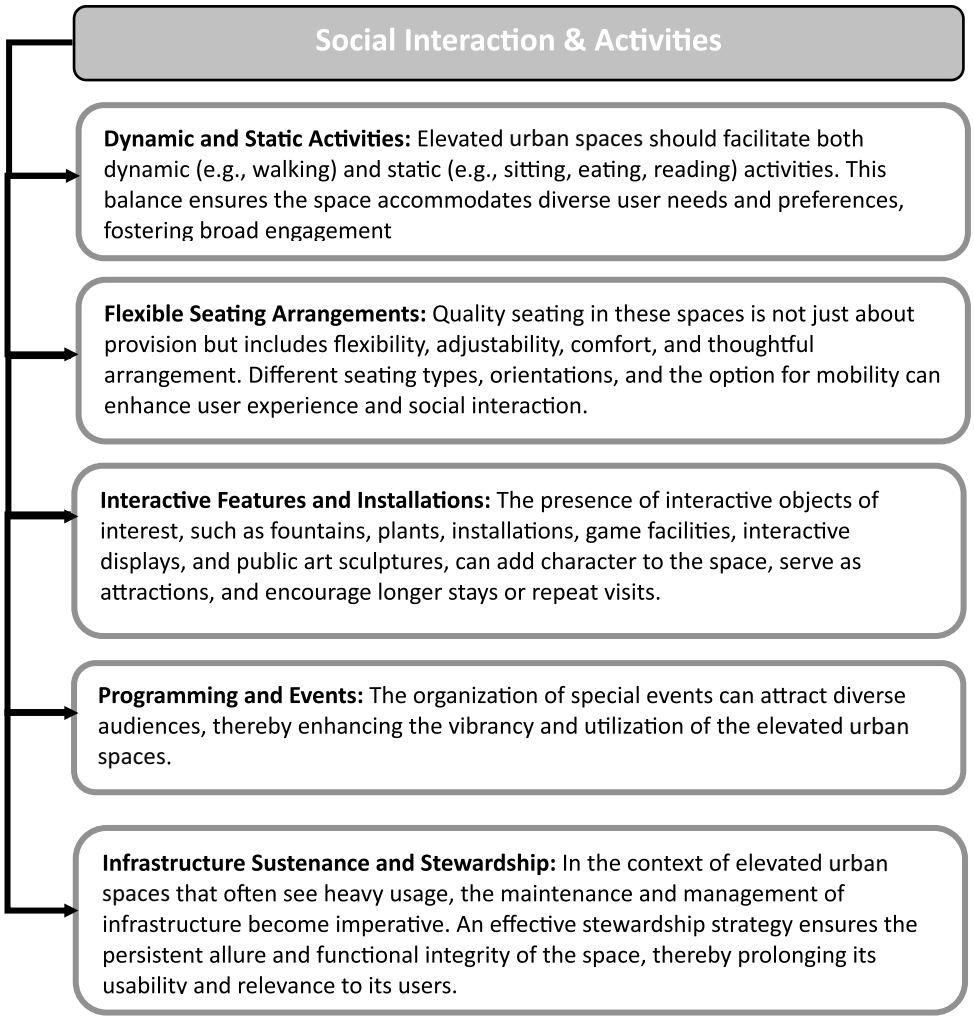


Fig. 9 Conceptual Framework Illustrating the Principal Aspects of Social Interactions & Activities for Resilient Elevated Urban spaces. Source: Author

In conclusion, the findings from Crossrail Place and the Sky Garden offer valuable lessons on the intricacies of circulation in elevated urban spaces (Fig. 8). The need for spaces that promote both exploration and comfort, while remaining accessible and adaptable, is critical to fostering successful urban environments. These case studies provide fresh perspectives on the role of elevated gardens, especially in a post-pandemic world, reinforcing the importance of thoughtful, inclusive design in enhancing user experiences and promoting community engagement.

4.3 Social interaction and activity

The findings from both the Sky Garden and Crossrail Place case studies offer a comprehensive understanding of how elevated urban spaces are utilised by the public, shedding light on the diversity of activities that occur within these urban environments (Fig. 9). These spaces are highly valued by the public, providing opportunities for walking, socialising, and relaxation, all of which are critical components of urban life.

At the Sky Garden, the space's capacity to host up to 600 visitors underscores its potential for fostering significant social interaction. Observations revealed that walking was the most frequent activity, reinforcing existing research which posits that providing opportunities for walking is fundamental to the design of successful public spaces. In fact, 38% of the participants cited walking as their primary activity at the Sky Garden. Additionally, the study identified six distinct optional and social activities, with stationary activities—such as sitting, eating, and reading—ranking as the second most popular, with 32% of visitors engaging in these activities. This aligns with prior studies that highlight the importance of creating spaces that cater to both dynamic and static activities, ensuring that users can engage in a variety of social interactions and moments of relaxation [85, 86]. Visitors also engaged in viewing the cityscape and capturing photographs,

with panoramic views being a key attraction for many, particularly from the outdoor terrace, which is frequently highlighted as a prime spot for photography and sightseeing. However, this area's accessibility was often limited by weather conditions, reducing opportunities for outdoor experiences. One visitor commented, "The views are spectacular, but the outdoor terrace was closed during my visit due to rain, which was disappointing" (Female, aged 24 years, UK resident).

During the pandemic, a significant reduction in visitor numbers was observed at the Sky Garden, reflecting the global trend of reduced public space usage during lockdowns. However, as Covid-19 restrictions eased, the space saw a resurgence in activities, particularly those centred around relaxation, such as eating, drinking, and chatting. This resurgence supports the view that public spaces designed to encourage relaxation and social interaction are vital to urban social life, especially in the wake of global crises [85]. Special events hosted at the Sky Garden, such as live performances and art exhibitions, further demonstrated the space's programmability, attracting a diverse audience and emphasising the role of temporary events in enhancing public engagement [86, 87]. One participant noted, "The music event was a great way to unwind after work, and it brought a lot of different people together" (Male, aged 30 years, London resident). Nevertheless, concerns regarding the high cost of food and beverages on-site were raised, highlighting that economic accessibility is an essential factor in ensuring that public spaces remain inclusive and regularly used by the wider community. "The prices for food and drinks were exorbitant. It discourages frequent visits, especially for families," remarked one visitor (Male, aged 28 years, UK resident).

Crossrail Place presented a contrasting picture during the pandemic, as the number of visitors actually increased by 25%. This spike in visitation can be attributed to the psychological benefits that natural spaces provide during periods of stress and uncertainty. The space became a refuge for activities such as reading, family picnics, and relaxation, as it offered a sense of security and tranquillity amidst the challenges of the pandemic. Research indicates that natural environments significantly enhance mental well-being, especially during times of crisis, and Crossrail Place's design clearly fostered this by providing a safe, well-ventilated, and accessible environment [88, 89]. A participant noted, "During the pandemic, it became a go-to place for our family picnics. It was a sanctuary from the stress of the city" (Female, aged 35 years, Canary Wharf resident). The garden's inviting design encouraged longer stays, particularly among families, who valued its sense of calm and connection to nature. The increase in family visits and longer stays also highlights the importance of social infrastructure, such as seating and interactive elements, in creating inviting and functional urban spaces.

Seating arrangements at Crossrail Place played a crucial role in encouraging social interaction. Previous studies have emphasised that seating organisation—whether through the flexibility of movable furniture or the strategic positioning of benches—enhances social activity and encourages longer stays [66]. The garden's seating varied from simple benches to more dynamic seating options, catering to both individual visitors and social groups. The addition of interactive objects, such as installations inspired by the Jardin Majorelle in Marrakesh, attracted new visitors and activities, further demonstrating that public spaces benefit from elements that engage and captivate users. These installations not only contributed to the aesthetic and cultural value of the space but also encouraged visitors to return, often bringing friends or family members along, thereby fostering a deeper connection with the space [66]. One participant said, "The art installations really make the space feel alive, and I find myself coming back with friends to experience it again" (Male, aged 31 years, Canary Wharf resident). However, increased foot traffic led to maintenance challenges, underscoring the importance of ongoing upkeep in ensuring the longevity and quality of public spaces.

Both case studies demonstrate that the design of elevated urban spaces must be flexible to accommodate various user needs. A balance between dynamic activities, such as walking (cited by 38% of Sky Garden visitors), and static ones, like sitting or observing, is essential to create spaces that cater to a diverse public. Flexibility in design also aligns with universal design principles, which emphasise the need for equitable use and adaptability in public spaces to ensure they are accessible to all, regardless of physical ability or socio-economic status [85]. Furthermore, the findings highlight that temporary installations and events can significantly enhance the appeal of public spaces, providing opportunities for engagement while maintaining a sense of place and continuity. Such events contribute to the vibrancy and cultural richness of these urban environments, making them attractive not only to daily visitors but also to tourists and event-goers.

In conclusion, the insights gained from both the Sky Garden and Crossrail Place reinforce the importance of designing elevated urban spaces that promote social interaction, relaxation, and inclusivity. These spaces not only serve as urban refuges but also play a crucial role in supporting mental well-being and fostering a sense of community. The lessons from these case studies contribute valuable knowledge for future design and research, particularly in understanding how elevated spaces can adapt to the evolving needs of urban populations while maintaining flexibility and inclusivity [85, 87, 89]. Both spaces exemplify the potential of well-designed urban environments to accommodate a wide range of activities, enhancing public life and providing critical spaces for social interaction in a fast-paced world.

4.4 Security and safety

Security and safety play crucial roles in elevated urban spaces, and the findings from both the Sky Garden and Crossrail Place case studies provide valuable insights into these aspects. At the Sky Garden, a strong visible security presence was perceived as a deterrent to illicit activities, with the majority of participants expressing a heightened sense of safety. This is consistent with previous research, which highlights the positive impact of visible security on users' perceptions of safety in public spaces [77]. However, approximately 25% of participants reported discomfort due to constant surveillance, with one individual stating, "It feels like someone is watching you all the time, and that takes away from the relaxation" (Male, aged 27 years, London resident). This reflects earlier findings that excessive security can lead to a sense of intrusion, negatively affecting the user experience [77]. Thus, achieving a balance between security and user comfort is essential in the design of elevated urban spaces to ensure that privacy and freedom are respected.

In addition to security concerns, access to the Sky Garden was restricted by the mandatory online booking process. Although this system helped manage crowd control, it also created barriers for spontaneous visits. Many participants noted that the process could be streamlined to improve accessibility, as procedural ease is crucial for public space usability [72]. "The booking system makes it feel more exclusive, but at the same time, it's a bit of a hassle," commented one visitor (Female, aged 30 years, UK resident). During the pandemic, the management introduced additional safety protocols, including a one-way circulation system and floor markings to maintain social distancing, which were generally well-received by visitors. These measures demonstrated adaptability in design, addressing the immediate need for social distancing while maintaining user flow within the space.

In contrast, Crossrail Place offered a more naturally secure environment during the pandemic due to its open-air design and ample ventilation. Many visitors appreciated the garden's spaciousness and airflow, with one participant stating, "The open layout made me feel much safer here than in other public spaces during the pandemic" (Male, aged 35 years, Canary Wharf resident). This response aligns with research that underscores the psychological and health benefits of open, natural spaces in reducing stress during crises [90, 91]. The garden's natural elements, including its integration of greenery and air circulation, made it a preferred destination for relaxation and mental well-being during the pandemic. The demand for such well-ventilated spaces is expected to grow in the future as cities continue to address public health concerns.

The study's findings also point to a shift in the design priorities for roof gardens in a post-pandemic world, with many participants advocating for more open and ventilated spaces. This trend aligns with the global movement toward vertical greening, which not only enhances environmental sustainability but also offers significant social and psychological benefits to urban populations [90, 91]. Participants commented on the importance of spaces like Crossrail Place in providing refuge from the dense urban environment, with one noting, "It's such a great escape from the city below. I hope we see more of these kinds of spaces in the future" (Female, aged 28 years, working in Canary Wharf).

As cities evolve, the integration of nature into urban environments, particularly through vertical greening and roof gardens, will be crucial in ensuring both environmental and social resilience. However, the effective management of these spaces necessitates innovative approaches to safety and risk management. The building industry must adopt new

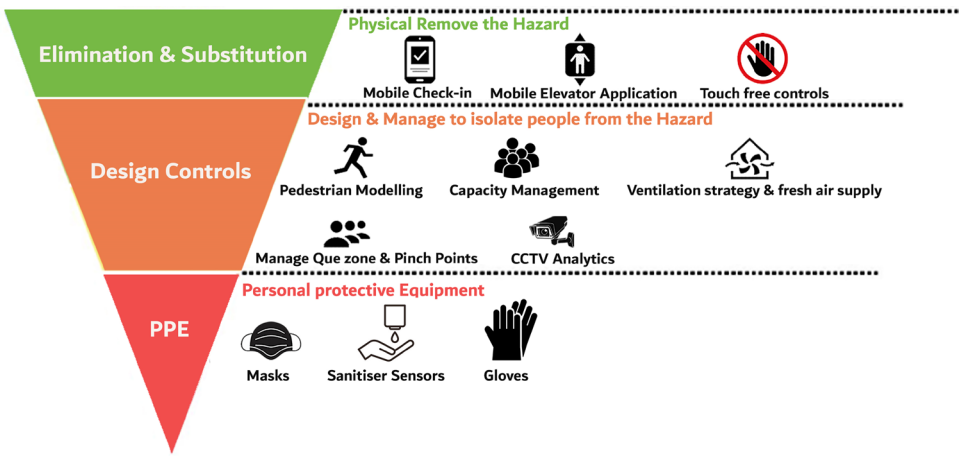


Fig. 10 The Hierarchy of controls is a commonly accepted system for reducing risk. The icons to the right represent some of the specific solutions that can be implemented in the vertical social space to effectuate each control action. Source: Author

strategies that combine operational, technological, and architectural innovations to address future public health challenges and enhance the resilience of urban spaces [92].

A particularly relevant model for managing risk in elevated urban spaces is the 'inverted pyramid of controls,' a widely recognised hierarchical framework for risk mitigation in public health and safety (figure 10). The pyramid categorises control measures by their effectiveness, with the most sustainable and impactful solutions, such as hazard elimination and substitution, positioned at the top, and less effective, short-term solutions, like personal protective equipment (PPE), at the base [94]. The principle underlying this model is that the higher a solution is placed on the pyramid, the more effective and enduring it is in controlling risks.

At the top of the pyramid are elimination and substitution, the most effective control measures that focus on removing the hazard or substituting it with safer alternatives. In elevated urban spaces, this might involve strategies like using mobile check-ins to reduce physical contact, touch-free elevator controls, and redesigning space layouts to eliminate congestion points [93, 94]. For instance, mobile elevator applications could allow visitors to move through spaces without touching shared surfaces, reducing contamination risks.

Following elimination and substitution, design controls form the next tier, focusing on designing spaces to isolate people from hazards. Key strategies here include pedestrian modelling to analyse foot traffic and avoid overcrowding, capacity management to prevent overuse, and implementing a ventilation strategy with fresh air supply to maintain healthy airflow [94]. For example, Crossrail Place's well-ventilated and open design provided a natural solution to the challenges posed by Covid-19, effectively isolating visitors from potential airborne risks without heavily relying on restrictive physical controls [93, 94].

The operational controls category within this tier would include methods like managing queue zones and pinch points, where spacing and movement could be controlled more naturally through design rather than enforced with personnel. CCTV analytics could assist in monitoring visitor flow without overtly intrusive surveillance, thus enhancing security without compromising the comfort of visitors [94].

At the base of the pyramid is PPE, including items like masks, hand sanitiser sensors, and gloves, which, while useful, are considered less effective than design or elimination measures in the long run. PPE has been essential during the pandemic but is not a sustainable solution for risk mitigation in the long term [93, 94]. One participant commented, "It's good that masks and sanitiser are available, but I hope the focus shifts to more permanent solutions like better ventilation" (Male, aged 31 years, London resident)

By applying the inverted pyramid approach, cities can prioritise more sustainable and effective measures to manage risks in elevated urban spaces, focusing on solutions that are built into the design of the space itself. This approach not only ensures long-term safety and resilience but also enhances the overall user experience by minimising the need for intrusive measures that may disrupt the atmosphere of the space.

The Sky Garden and Crossrail Place both implemented robust safety measures during the pandemic, yet their approaches differed. The Sky Garden's stringent safety protocols and controlled access were successful in minimising health risks, but they contributed to a somewhat over-regulated atmosphere. As one visitor noted, "The security is very tight, which is reassuring but also a little too much at times" (Female, aged 26 years, London resident). In contrast, Crossrail Place capitalised on its open-air design to mitigate health risks without the need for excessive visible security, creating a more relaxed and natural environment. One participant commented, "This space feels safer because of the fresh air and openness, without needing all the extra measures" (Male, aged 33 years, Canary Wharf resident.

The insights from these case studies suggest that future designs of elevated urban spaces should prioritise flexibility, openness, and ventilation to adapt to evolving public health needs. Security and safety measures must be carefully integrated to avoid overwhelming users or diminishing the atmosphere of the space. Furthermore, the psychological benefits of incorporating natural elements and providing spaces for solitude and mental rejuvenation are increasingly acknowledged as essential components of urban life, especially during periods of crisis. As one participant aptly summarised, "It's not just about feeling physically safe, but also about having a space that supports your mental well-being" (Female, aged 35 years, London resident).

4.5 Publicness and territorial rights

Perceptions of publicness and territorial rights in elevated urban spaces are complex and multifaceted. From the case studies of the Sky Garden and Crossrail Place, it becomes clear that various management practices and spatial designs heavily influence how users perceive the publicness of these spaces.

In the case of the Sky Garden, most participants identified the space as a 'private-public' area, with many perceiving it to be more private than public. Factors influencing these perceptions include mandatory pre-booking, stringent security protocols, and the association of certain areas, such as seating spaces, with commercial entities. One participant expressed the following sentiment: "The space feels more private, given the requirement of pre-booking and the constrained one-hour visiting slot. These factors create a certain pressure, even though I've never been asked to vacate the premises" (Female, aged 26 years, London resident). These constraints tend to diminish the spontaneous and relaxed experience typically associated with public parks, thus negatively impacting the sense of freedom and openness.

This aligns with existing literature, which suggests that management practices, including how access is controlled and how spaces are regulated, can significantly impact perceived publicness [82]. The Sky Garden's association with commercial ventures and its highly regulated access requirements contribute to a space that feels more restricted, despite being nominally open to the public. *To address these issues, introducing private-public partnerships that encourage participatory design would allow the public to become more engaged in shaping the design and regulations of the space. This could replace restrictive signs listing prohibitions with positive signage, indicating permissible activities, which would make visitors feel more welcome. Additionally, security presence could be maintained through CCTV and security guards stationed subtly around the area to ensure safety without creating a sense of constant surveillance.*

In contrast, while Crossrail Place also employs management practices, it was less frequently described in terms of restricted access. Participants generally felt that the space offered more freedom, although some noted that certain activities common in traditional public parks were limited. For instance, one visitor commented, "I can't engage in the same activities as in a public park like Hyde Park. Picnics, sitting on the grass with my dog, and listening to music aren't possible here" (Female, aged 28 years, Canary Wharf resident). Despite these limitations, Crossrail Place was perceived as safer and more accessible, reflecting a compromise between safety measures and public freedom. *To further enhance this sense of publicness, management could introduce small, accessible areas where visitors can engage in activities typically associated with public parks, helping foster a stronger community feel.*

While Crossrail Place was described as having a more open atmosphere compared to the Sky Garden, the management of access and the ambiguity surrounding territorial rights still affected how visitors perceived their freedom in the space. This ambiguity is particularly characteristic of privately-owned public spaces, where users are often uncertain about what activities are permitted. A participant remarked, "Crossrail Place feels more like a public park, even though it has some restrictions" (Male, aged 32 years, Canary Wharf worker). This comment underscores the balancing act between safety, management, and public access that both locations must navigate [72].

The differing perceptions of publicness between these two spaces highlight the influence of management practices on accessibility and user experience. The Sky Garden's security protocols and pre-booking system have resulted in a

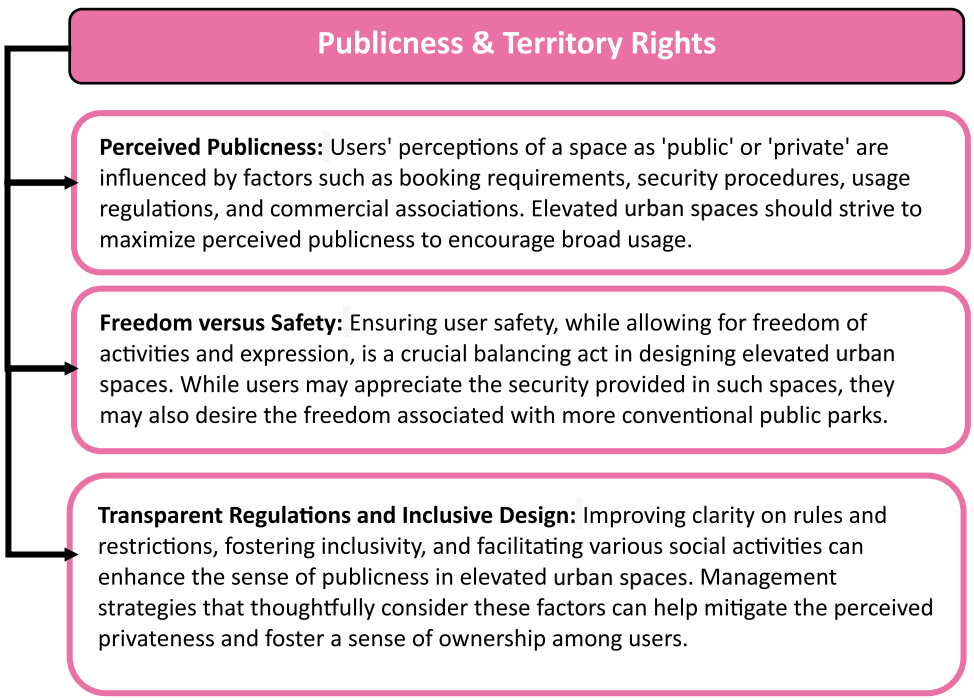


Fig. 11 Conceptual Framework Illustrating the Principal Aspects of Publicness and Territory Rights for Resilient Elevated Urban spaces. Source: Author

more controlled, less spontaneous environment, making it feel more exclusive. In contrast, Crossrail Place, though still managed, allows for greater flexibility and is perceived as more in line with traditional expectations of public space, though with some limitations.

Design and management strategies for elevated urban spaces should aim to balance safety and order with the users' desire for freedom and publicness (figure 11). Improving transparency regarding rules, relaxing pre-booking requirements, and reducing the association of seating spaces with commercial entities could help mitigate the sense of privateness and make these spaces feel more inclusive and accessible [72, 82]. For instance, creating unmarked, non-commercial seating areas could foster a greater sense of ownership among users. Promoting transparency about permissible activities would also help reduce the ambiguity that affects user perceptions. One key consideration should be fostering inclusiveness by encouraging a sense of public ownership, where users feel they can freely engage in a variety of social activities.

Future research should investigate the effectiveness of such strategies in mitigating perceptions of restricted access and their overall impact on user experiences in elevated urban spaces. This includes studying how changes in management practices, such as reducing the reliance on pre-booking systems, might alter perceptions of territorial rights and improve the inclusivity of these spaces. By addressing these issues, designers and managers can help ensure that elevated urban spaces are not only safe but also truly public, offering a balance of freedom and security that fosters a sense of community engagement.

4.6 Competent management

Effective management of elevated urban spaces requires fostering inclusivity through flexible, light-touch regulations rather than rigid restrictions that could exclude certain groups or behaviours. Management should adopt a nuanced approach, focusing on risk assessments that target genuine threats or nuisances rather than perceived undesirable characteristics (Fig. 12). This ethos ensures that the space remains open and welcoming to diverse user groups [4, 9, 11]. As one study highlights, rather than banning people, activities, or animals outright, regulations should be framed around managing actual risks and ensuring safety [9].

Innovative management strategies are essential in enhancing the vibrancy of these elevated spaces. Limiting constraints to those that are justifiable and necessary allows users to feel a sense of ownership and involvement, turning them into active stewards rather than passive participants. Encouraging user participation in the stewardship of these spaces is crucial to fostering a sense of communal engagement and responsibility. For example, designated areas for

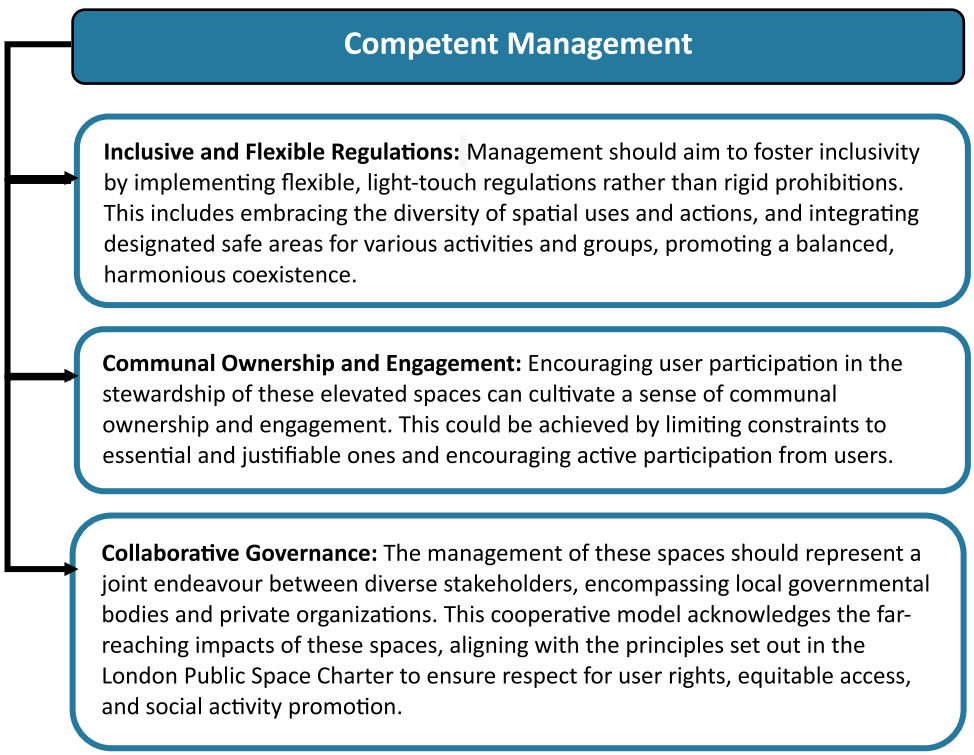


Fig. 12 Conceptual Framework Illustrating the Principal Aspects of Competent Management for Resilient Elevated Urban spaces. Source: Author

specific activities, such as sections for smokers, pet owners, or even spaces for ball games and skateboarding, can be integrated into the design. This promotes a harmonious coexistence within the space, ensuring all groups can enjoy the environment without clashing over territory or activities [4].

A cooperative management model between local councils and stakeholders is another critical component in ensuring these elevated spaces serve their full potential. Relying solely on investors or private stakeholders can limit the public benefit of such spaces, as their management may be primarily driven by commercial interests. Instead, a hybrid partnership between local councils, boroughs, and private stakeholders should be developed. Such a model ensures that the management of these spaces aligns with broader urban goals, including environmental strategies, the enhancement of neighbourhood ambiance, and the improvement of both physical and mental wellbeing for residents [95]. These spaces are often considered city landmarks, and their impact extends beyond the immediate area they occupy, contributing significantly to the character and sustainability of urban environments.

Aligning the governance of these spaces with the London Public Space Charter ensures that user rights are respected, equitable access is maintained, and a wide range of social activities are encouraged. The principles of the charter advocate for inclusivity, transparency in management, and the support of diverse activities within public spaces [4]. By adhering to these principles, the management can ensure that elevated urban spaces remain dynamic and inclusive, thus enriching the urban experience for a wide range of users.

Balancing inclusivity with necessary regulation is fundamental to the success of these elevated spaces. Creating an environment that fosters community participation and establishing cooperative governance models ensures that these spaces not only contribute to the physical environment but also support the social, economic, and psychological wellbeing of urban dwellers [96]. Encouraging local residents to take part in the governance of these spaces, perhaps through community boards or partnerships with local groups, could further deepen the sense of belonging and communal ownership.

Future research should focus on refining these management strategies to meet the evolving needs of urban societies. As cities continue to grow and densify, the role of elevated urban spaces will become increasingly important. Research can investigate how these spaces adapt to changes in urban environments, including shifts in population demographics, environmental pressures, and social needs. Additionally, understanding how user participation in management impacts the long-term sustainability and vibrancy of these spaces will be key to their future success [9, 96].

4.7 Participatory Co-design approach

A participatory co-design approach is essential for developing elevated urban spaces, involving designers, developers, city councils, local communities, and the public. This method ensures that diverse perspectives are considered, leading to spaces that are inclusive, accessible, and stimulating [97, 98]. Drawing from the case studies of Sky Garden and Crossrail Place, the benefits of user feedback in identifying both design merits and areas for enhancement are clearly demonstrated.

For instance, in the case of the Sky Garden, feedback from participants proved invaluable in identifying areas ripe for improvement. While there was widespread appreciation for the infusion of natural elements, users also pointed to aspects such as seating arrangements, plant variety, and overall site layout as needing further attention. Recommendations for additional features promoting social interaction and physical activity were coupled with suggestions for more tranquil spaces for individual pursuits. This balance underscores the necessity of a participatory co-design approach in crafting spaces that genuinely resonate with the needs and desires of users [97]. As one participant noted, "The garden is beautiful, but I wish there were more diverse plants and better seating options that allow for both social interaction and quiet reflection" (Female, aged 28 years, London resident).

Similarly, the Crossrail Place case study revealed the value of user feedback in informing practical design enhancements. Participants highlighted a lack of shaded areas, constrictive pathways, and uncomfortable seating benches as aspects that could be improved. Concurrently, several suggestions were made regarding the incorporation of water features, enhanced plant diversity, and new activities that would enrich the space's functionality. However, some participants also expressed concerns about overcrowding and the potential for excessive noise if too many new features were introduced, highlighting the importance of maintaining a balance between vibrant social activity and peaceful retreats [99]. One visitor commented, "It's a great space, but I worry that adding too many new activities could make it too crowded and noisy" (Male, aged 35 years, Canary Wharf worker).

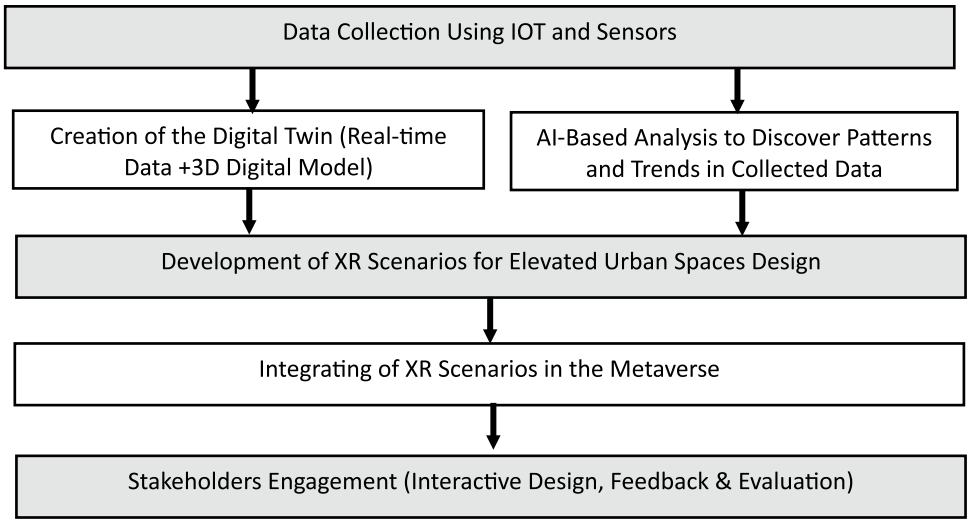


Fig. 13 Conceptual Flow Chart for an Interactive Participatory Design model for Resilient Elevated Urban Spaces Design. Source: Author

The employment of a participatory co-design approach fosters not only more inclusive and accessible spaces but also amplifies users' sense of ownership and attachment to these areas. By actively engaging stakeholders in the design process, these spaces are more likely to meet the evolving needs of the communities they serve. This method cultivates a dynamic relationship between the users and the space, ensuring that the designs remain relevant and responsive over time.

Incorporating new technologies such as Virtual Reality (VR) and Extended Reality (XR) into the co-design process can further engage the public and enhance design outcomes. These technologies allow users to provide real-time feedback, enabling designers to refine their projects before physical construction begins [100]. XR offers the possibility for users to experience the space in a virtual world, suggesting improvements and testing design decisions in real-time. As a result, this method can avoid costly mistakes and ensure that the final design aligns with users' preferences and needs. This participatory methodology, coupled with emerging technologies, can elevate the design process and ensure that the final product better serves its community (Fig. 13). As research suggests, the integration of XR into the design of elevated urban spaces provides a strategic intervention, identifying opportunities for improvement and enhancing the quality of the space [100].

Moreover, the participatory co-design approach should be seen not as a one-time event but as a continuous process. As elevated urban spaces evolve and user needs change, ongoing dialogue between stakeholders—users, designers, and local councils—ensures that the spaces remain vibrant and relevant [98]. This iterative approach allows for routine feedback collection and adaptation, fostering a resilient design that evolves alongside the community it serves. As one designer commented, "The beauty of this approach is that we can continue to refine the space long after it's built, ensuring it always meets the needs of its users" (Designer, aged 40 years, project lead).

In conclusion, a participatory co-design approach is key to the successful development and ongoing management of elevated urban spaces. By actively engaging a wide range of stakeholders, including the public, in the design process, it fosters spaces that are inclusive, accessible, and adaptable. As new technologies like VR and XR become more integrated into the design process, the ability to capture real-time feedback and make data-driven decisions will further enhance the outcomes of co-design efforts. This approach ensures that elevated urban spaces remain relevant, attractive, and responsive to user needs, while also cultivating a strong sense of community and place attachment [99, 100].

5 Conclusion

This paper contributes significantly to the discourse on urban design in hyperdense cities by proposing a comprehensive framework for resilient elevated green spaces. The research draws on a rich literature review, examining the historical evolution and contemporary significance of typologies such as sky gardens, rooftop gardens, elevated parks, courtscrapers, and integrated skywalks. These spaces have been shown to play vital roles in enhancing urban resilience, improving

public health, and fostering social well-being, particularly in the context of rapid urbanisation and challenges posed by the COVID-19 pandemic.

The framework developed is grounded in an in-depth analysis of two case studies—Sky Garden at 20 Fenchurch Street and Crossrail Place Roof Garden in Canary Wharf, London. These examples highlight how unique architectural features, biophilic design, accessibility, and circulation dynamics can create functional and adaptable elevated green spaces within hyperdense urban environments. Semi-structured walk-along interviews conducted at these sites provided valuable qualitative data, identifying critical areas for improvement such as inclusivity, accessibility, and the promotion of social interaction.

This research bridges a gap in the literature by synthesising existing knowledge with empirical insights, offering a practical, context-specific framework for the design and management of elevated green spaces. Key principles such as accessibility, circulation, publicness, safety, and effective management are essential to successfully integrating these spaces into urban fabric and ensuring they meet the evolving needs of city dwellers.

The findings hold significant implications for urban planners, architects, and policymakers. They provide actionable insights into addressing design challenges, enhancing public access, and integrating natural elements into urban spaces. By fostering urban biodiversity, mitigating the urban heat island effect, and improving both mental and physical well-being, elevated green spaces have the potential to become critical components of resilient urban design strategies in the future.

Moreover, this research sets the stage for future inquiry into the use of emerging technologies such as VR and XR in participatory co-design processes. These technologies could revolutionise how the public engages with the design of elevated spaces, ensuring that such environments remain adaptable and responsive to the shifting demands of urban life. The lessons drawn from the Sky Garden and Crossrail Place Roof Garden underscore the transformative potential of well-considered design, positioning elevated green spaces as integral to the creation of sustainable, liveable, and resilient urban landscapes.

To operationalise these findings, urban planners should prioritise the integration of flexible, open-access features in the design of elevated green spaces to maximise inclusivity. Policymakers are encouraged to reduce regulatory barriers, such as pre-booking requirements, which can limit spontaneous public engagement. Further, planners should incorporate biophilic elements and consider non-commercial seating options to enhance public ownership of these spaces. Implementing participatory design practices, supported by XR and AI, can enable the public to have a direct role in shaping and regulating these spaces. These recommendations will foster a sense of community ownership and ensure that elevated green spaces serve as inclusive, adaptive, and resilient components of urban landscapes.

Author contributions Author Contributions: Methodology, A.E. and T.H.; Software, A.E. and G.B; Investigation, A.E.; Resources, A.E and T.H.; Data curation, A.E and GB.; Writing—original draft, A.E.; Writing—review & editing, A.E, GB and T.H.; Visualization, A.E.; Supervision, T.H and G.B.. All authors have read and agreed to the published version of the manuscript.

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Data availability The datasets used and analysed during the study are available from the corresponding author upon reasonable request.

Declarations

Informed consent Informed consent was obtained from all subjects involved in the study.

Competing interests The authors declare no competing interests.

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