

Review

The Sustainability of Tall Building Developments: A Conceptual Framework

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Abstract: As cities cope with rapid population growth—adding 2.5 billion dwellers by 2050—and grapple with expansive sprawl, politicians, planners, and architects have become increasingly interested in the vertical city paradigm. This paper reviews and examines shortfalls of tall buildings found in the literature to inform future developments. The paper gathers a vast amount of fragmented criticism and concerns, and organizes them around the three pillars of sustainability: social, economic, and environmental. Mapping out the “unsustainable” aspects forms the foundation for addressing them in future research and tall building developments.

Keywords: sustainability; high-rise developments; economic shortfalls; social failure; environmental problems

1. Introduction

1.1. What Is a Tall Building?

There is no universally accepted definition of a “tall building”. Governments around the world differ in how they define “tall buildings”. For example, German regulations define “tall buildings” as buildings higher than 22 m (72 ft) with room for the permanent accommodation of people [1]. City officials derived this limit from the length of ladders used by the firefighters. Leicester City Council in the UK defines a tall building as any structure over 20 m/66 ft in height, and/or a building of any height that is substantially higher than the predominant height of the buildings in the surrounding area, and/or a building that would make a significant impact on the city’s skyline [2]. In Ireland, Cork City defines tall buildings as buildings of 10 stories and higher [3]. The ASHRAE (American Society of Heating, Refrigerating, and Air-conditioning Engineers) Technical Committee for Tall Buildings defines them as buildings higher than 91 m/300 ft [4].

A similar definition problem is found when we search for definitions of a high-rise building, a tower, or a skyscraper. However, in most cases, differences in definitions are insignificant for this research. For the sake of simplicity, brevity, and based on research by the Council on Tall Buildings and Urban Habitat (CTBUH), the Emporis, and others [5–9], this paper embraces the following definitions:

- A tall building, a high-rise, or a tower is a 50 m+ (164 ft+) building.
- A skyscraper is a 150 m+ (328 ft+) building.
- A supertall or ultra-tall is a 300 m+ (984 ft+) building.
- A megatall is a 600 m+ (1967 ft+) building.

1.2. The Tall Building Construction Boom

Since 1990, most cities have seen a steady increase in urban dwellers. In 1990, 43 percent of the world’s population (2.3 b/5.4 b) lived in urban areas, and by 2015, this had grown to 54 percent (4.0 b/7.4 b). By 2030, the United Nations expects that 60 percent of the world’s population (5.1 b/8.5 b)

will live in urban areas; and in 2050, 80 percent of the world's population (7.7 b/9.7 b) will live in urban areas. At the time of this writing (2017), the urban population constitutes about 55 percent of the world's population (4.1 b/7.5 b). Therefore, by 2050, urban population will increase about 2.5 billion people. That is, the projected urban population increase is 80 million people a year. This is equivalent to about 1.5 million new urban dwellers a week or 220 thousand a day. Geographically, this would be the equivalent of building eight mega cities (defined as cities with 10 million people and greater) a year. By 2050, in addition to having a greater number of mega cities, currently existing mega cities of the world, particularly those in Asia, Africa, and Latin America will house greater populations, ranging from 30 to 50 million people or more [10].

Although tall buildings are not the only way to accommodate the increasing urban population—it is possible to do so with mid-rise buildings—cities are constructing tall buildings across the globe rapidly (p. 9 [10]). Indeed, since 2000, cities have constructed more tall buildings than it did in the previous 115 years—Year 1885 is considered the birth date of skyscrapers [10]. These new buildings are also reaching record-breaking heights. For example, before the year 2000, we constructed only 24 supertalls. Since that time, over 84 supertalls have been completed. Further, from 1930 to 2001, the world has completed 282 200 m+ buildings (an average of about four buildings per year), while from 2002 to 2015, that number was 679 (an average of 52 buildings per year). In the past decade, a new height category was created for skyscrapers known as “megatalls” that are over 600 m (1979 ft) tall. Three megatalls have already been constructed, and several more are currently under construction. In recent years, the “super mega-tall”, category has arrived as buildings such as the 1000 m+ Jeddah Tower in Saudi Arabia are built [11]. The driving forces for building tall include massive migration from rural to urban areas, rapid urban renewal, skyrocketing land prices, active agglomeration, globalization and global competition, human aspiration, symbolism, and ego [10].

Certainly, cities around the globe are experiencing a tall building boom. Asia is clearly leading the way in this regard, with unprecedented tall building construction occurring in cities such as Shanghai, Beijing, Nanjing, Shenzhen, Guangzhou, Dalian, Wuxi, Hong Kong and Taipei (Greater China); Tokyo, Osaka and Nagoya (Japan); Bangkok, Pattaya and Nonthaburi (Thailand); Seoul, Busan and Incheon (South Korea); Kuala Lumpur (Malaysia); Jakarta (Indonesia); Makati, Quezon and Manila (Philippines); Mumbai (India) and Singapore, among others. Middle Eastern cities such as Dubai, Jeddah, Doha, Mecca, Tel Aviv, and Beirut also have been vigorously building tall. For example, Dubai has built the world's tallest building, and Jeddah is building the next tallest. North American cities such as New York, Chicago, Miami, Los Angeles, San Francisco, Toronto, and Calgary are experiencing a renewed interest in building skyscrapers. South American cities (e.g., Santiago, Cartagena, Buenos Aires, and São Paulo) and Central American cities (e.g., Panama City, Mexico City, Monterrey, and Guadalajara) also are building more tall buildings. Even African cities such as Johannesburg, Pretoria, Sandton, Dar es Salaam, Nairobi, and Lagos are increasingly embracing the tall building typology [12,13].

1.3. Critiques of Tall Building Developments

Numerous scholars have pointed out serious concerns about tall buildings. For example, Ken Yeang, a leading figure on sustainable tall building developments, stated that, “At the outset, we should be clear that the skyscraper is not an ecological building type. In fact, it is one of the most un-ecological of all building types” (p. 84 [14]). He illustrates the notion of “uneccologicalness” by arguing that tall buildings require excessive materials and sophisticated structural systems to build so that they are able to withstand greater wind forces that prevail at higher altitudes. They also demand greater energy to construct, operate, and maintain. Many of these problems stem from the vertical orientation of this building typology.

Earlier, Christopher Alexander and colleagues in their seminal book *A Pattern Language* rejected the high-rise city altogether as a viable human habitat. They passionately explained their reasons (p. 114 [15]).

Pattern 21: FOUR-STORY LIMIT. There is abundant evidence to show that high buildings make people crazy. Therefore, in any urban area, no matter how dense, keep the majority of buildings four stories high or less. It is possible that certain buildings should exceed this limit, but they should never be buildings for human habitation.

Similarly, Léon Krier, a prominent proponent of the New Urbanism movement, explains in his book *The Architecture of Community* that buildings should have no more than five floors [16]. James Howard Kunstler, a widely respected figure in urban geography, argues that skyscrapers generate urban pathologies. They also demand lots of energy and are expensive to retrofit. Ergo, when oil peak and climate change prevail, skyscrapers will become irreparable relics [17].

Likewise, the Danish architect and urban designer Jan Gehl in *Life Between Buildings* (1971) [18] and *Cities for People* (2010) [19] critiqued high-rise cities and praised low-rise ones in various parts of the world for they emphasize the value of human scale and provide abundant opportunities for healthy social interaction. The well-known Jane Jacobs in *The Death and Life of Great American Cities* (1963) praised human scale environments that foster an active pedestrian life [20]. Also, Hans Blumenfeld in his influential work *The Modern Metropolis* (1971) denounced tall buildings because they damage the historic fabric of cities [20].

1.4. Purpose of the Study

Indeed, upon scanning the social science, architecture, and planning literatures we find a plethora of scholars who critique tall buildings. However, these views are scattered and do not follow any particular order or a conceptual framework. This paper intends to identify, collate, and consolidate fragmented concerns and critiques of tall building developments and presents them in an accessible manner. It aims to help architects and planners to attain higher levels of sustainable tall building developments by avoiding and addressing common “unsustainable” aspects. As such, this paper forms a knowledge base that is essential to learn and examine unsustainable practices in tall buildings. It offers a detailed “check list” of topics and issues that are important to the sustainability of tall building development. It alerts about critical and unexamined issues or just simply offers a reminder of pitfalls and ill practices. The paper employs sustainability as a framework to consolidate critiques and pitfalls of tall building developments and uses sustainability’s three pillars (social, economic, and environmental) to guide the discussion.

The promise of the “sustainable tall” research is that given the large-scale problems of conventional skyscrapers, any improvements in their design, construction and contextual relationships with their cities will be significant. Since tall buildings serve a great number of people and place a great demand on the environment at large and the immediate infrastructure of transportation, sewer, and electrical grid, “sustainable” design may better serve tenants, mitigate environmental impacts and enhance integration with the city infrastructure. Ergo, as architects design taller buildings that serve more people and demand more from the environment and infrastructure, any improvement in their design and construction will benefit cities and denizens. The long life cycle of a skyscraper justifies careful and informed design, whether we apply for new buildings or in retrofitting aging ones. These accumulated factors have engendered a substantial demand for sustainable tall buildings.

1.5. Sustainability as a Framework

The concept of sustainability continues to be of paramount importance to our cities [21,22]. Planners, architects, economists, environmentalists, and politicians continue to use the term in their conversations and writings. The term “sustainability” frequently appears in academic literature, professional conferences and organizations, and in practice. For example, the American Planning Association (APA) continues to use this term in its discussions, publication, and programs. The APA’s Sustaining Places Initiative, a program dedicated to promoting sustainability in human settlements, has recently released several important reports that center on sustainability. Remarkably, *Sustaining*

Places: Best Practices for Comprehensive Plans (2015) by David R. Godschalk and David C. Rouse offers planners a detailed guide to creating comprehensive sustainable plans [23].

Similarly, the United Nations' World Urban Forum (WUF), the world's premier conference on urban issues, uses "sustainability" as a guiding theme to its myriad activities. Since its first meeting in Nairobi, Kenya in 2002, through the latest in Rio de Janeiro in 2016, the WUF uses the concept of "sustainability" as central to their agenda.

Importantly, WUF uses the term "sustainable" in each of its objectives as follows: [24]:

- Raise awareness of *sustainable* urbanization among stakeholders and constituencies, including the general public;
- Improve the collective knowledge of *sustainable* urban development through inclusive, open debates, sharing of lessons learned and the exchange of best practices and commendable policies; and
- Increase coordination and cooperation between different stakeholders and constituencies for the advancement and implementation of *sustainable* urbanization.

The comprehensiveness of the sustainability concept is apparent in one of the earliest and most frequently used definitions created by the United Nations' Brundtland Commission in 1987. The commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [25]. Concisely, this definition resonates the root meaning of the word "sustain", which is to "provide with nourishment" or to "keep going", as defined by Merriam-Webster Dictionary [26]. Therefore, in line with the urban planning profession, sustainability emphasizes the long-term implications of all human activities. It also presumes that resources are finite and that we should use them conservatively and wisely according to long-term priorities and consequences of the ways we use them.

Over the past three decades, sustainability has evolved and become even more comprehensive and complex. Planners, architects, and politicians have been applying expanded and diversified definitions of sustainability to almost all human activities, such as [27]:

- A sustainable future is one in which a healthy environment, economic prosperity, and social justice are pursued simultaneously to ensure the well-being and quality of life of present and future generations. Education is crucial to attaining that future.
- In essence, sustainable development is about five key principles: quality of life; fairness and equity; participation and partnership; care for our environment and respect for ecological constraints—recognizing there are 'environmental limits'; and thought for the future and the precautionary principle.

Therefore, sustainability addresses a wide-spectrum of planning and design issues (e.g., housing, economic growth, water, land, energy, waste recycling, transportation, tourism, parks, open spaces) and illustrates their interconnectedness. It helps us to adapt our activities to the constraints and opportunities of the natural systems we need to support our lives. It also assists in planning for "balanced community where urban centers prosper, natural landscapes flourish, and farming is strengthened as an integral component of our diverse economy and cultural heritage", as Rick Pruetz explains (p. 34 [28]). Notably, in his book *The Architecture of Community*, Léon Krier presents sustainable urbanism as "an ethical and civilizing vision of universal stature" (p. 101 [16]).

Sustainability offers an inclusive framework represented in its three conceptual pillars (the social, the economic, and the environmental) or the "3Ps" of people, profit, and the planet, where:

- "people" represents community well-being and equity;
- "profit" represents economic vitality; and
- "planet" represents conservation of the environment.

These pillars or dimensions are also expressed by the “3Es” of equality, economics, and ecology or what is known as the triple bottom line (TBL or 3BL). Sustainability seeks to balance these three dimensions across geographic scales—from individual habitats to neighborhood, community, city, region, country, continent, and the planet at large—and according to both short and long-term goals. Therefore, the centrality and comprehensiveness of sustainability suggest using it as an “umbrella” term that captures a wide-spectrum of practical projects under different agendas—“ecological”, “environmental”, “green”, “social” and “economic”—which all share the common thread of reducing harmful impact on the environment while delivering economically viable, healthy, and comfortable human habitats (Figure 1).

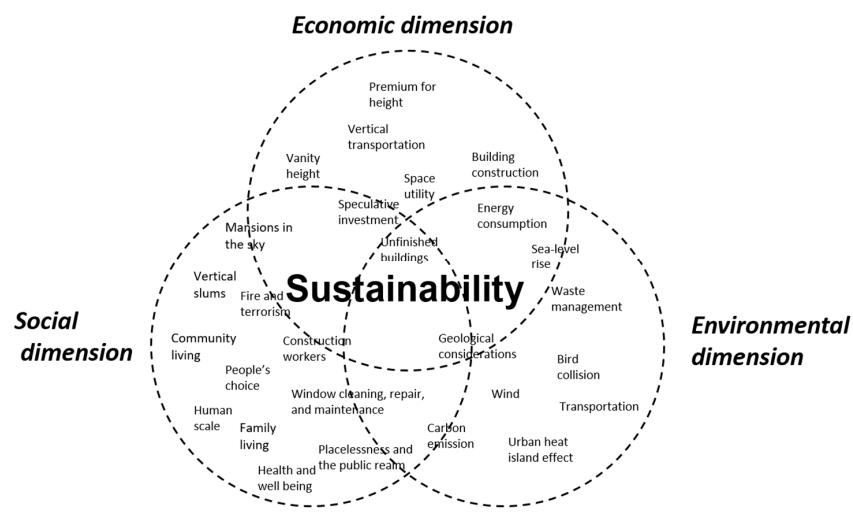


Figure 1. Using “Sustainability” as a guiding framework to organize the many issues related to tall building developments.

2. Social Dimension

Largely, social science literature reveals that people have multiple concerns about high-rise living including suitability for family living and raising children, neighborly relationships and helpfulness, personal behavior and comfort, perception of safety, tenants’ relation to outdoor spaces and connection to street life [29–38]. High-rises’ tenants often feel that they are cooped up in finite spaces of an encapsulated world that fosters loneliness. These environments may make inhabitants also feel claustrophobic, creating a rat-cage mentality. Further, high-rise living could promote poor interpersonal relationships and weak neighborly relationships that may result in a psychological depression. In some cases, the “isolated” nature of high-rise buildings could promote crime. Further, scholars argue that low-rise living is closer to nature and facilitates a stronger community-oriented social life [30]. As structures grow taller and taller, tenants may perceive that they become increasingly out of touch with the city life.

2.1. Family and Community Living

For children, tall buildings could be “vertical prisons” [30]. Children may feel in these buildings that they are confined and treated like “a pet on a short leash”. These buildings may offer day care centers and playgrounds “in the sky”; however, children lack spontaneous play and exploration that help them to thrive. Urban psychologists explain that high-rise living can hinder a toddler’s psychological growth. They suggest that one of the best ways for children (ages between 2 and 7) to become independent is by allowing them to gradually go out on their own to experience the real world (e.g., neighborhood, corner store, streetscape, playgrounds, friends and neighbors) and then return home, their haven. Such approach, however, is only attainable in a low-rise environment where parents

can see (and may hear) their children from their homes' windows. This interplay between dependence and autonomy that earns a child a sense of competence is missing in high-rise environments [37].

The presence or absence of recreational and social outdoor spaces in tall building developments significantly affects the overall residential satisfaction more than that in low-rise environments [31]. That is, tall buildings' residents lack front-yards, courtyards, and backyards, and hence public outdoor spaces are critically important for them. When these spaces are absent, residents are "forced" to spend more time indoors, where they may then experience overcrowding or being "imprisoned in the sky" [31,32]. Further, when vertical transportation is inadequate or frequently malfunctions, residents will feel discouraged to travel back and forth to amenities provided on the ground floor. Consequently, these amenities will be underused and residents may not reap the full benefits.

High-rises often create disjointed neighborhoods [29]. They are individualistic, introverted structures that make people feel they are living in "vertical silos", physically, socially, and psychologically. These buildings appear to be monolithic structures mushrooming in cities without respecting the socio-spatial order of their neighborhoods. When tall buildings are juxtaposed next to low-rise buildings, residents worry about the loss of privacy since windows and balconies loom over their backyards and shadow their gardens. In his article "The Consequences of Living in High-Rise Buildings", in the *Architectural Science Review journal* (2007), Robert Gifford details six types of fears found in high-rise living as follows [30]:

1. Residents fear that a family member or a loved child jumps from a window,
2. Residents may fear masses of "strangers" that share the same building or floor,
3. Residents fear a fire that may trap them in the building,
4. Residents fear a devastating earthquake that will topple the building over them,
5. Residents may fear becoming ill from communicable diseases generated by the masses who live there, and
6. Post 9/11, high-rise residents fear that their buildings become terrorist targets

Constantinos Apostolou Doxiadis, a reputable planner and architect, summed up these observations in his writing:

High-rise buildings work against man himself because they isolate him from others, and this isolation is an important factor in the rising crime rate. Children suffer even more because they lose their direct contact with nature and other children. High-rise buildings work against society because they prevent the units of social importance—the family, the neighborhood, etc., from functioning as naturally and as normally as in low-rise environments (p. 82, [30]).

Skyscrapers substantiate income and racial segregations by creating "vertical gated communities" (VGCs), which limit social interaction and promotion of social capital across socioeconomic groups. As is the case with "horizontal" gated communities, VGCs internalize residents' social activities that might otherwise invigorate the public realm and enliven street life. Further, high-rises are often the habitats of smaller household size (referring to the number of individuals living in a household) with fewer children. However, research indicates that the presence of a greater number of tenants and particularly children is critical to promote sense of community. Consequently, the chances of having lower sense of community in high-rise developments are greater than that in low-rise developments [31,32].

2.2. Disparity in Quality of Life

Tall building may serve a wide-range of tenants of various classes and incomes, including upper, middle, and lower classes. However, critiques have focused on tall buildings that cater to either the poor or the rich population. At one end of the spectrum, "vertical slums" have prevailed in poor neighborhoods, for example in the U.S public housing projects. Unfortunately, due to mismanagement, inadequate maintenance, and mediocre architectural design, these buildings suffered from difficult living conditions. They fell into disuse, and eventually, authorities demolished

these housing projects. Archetypal projects include the Pruitt–Igoe in Saint Louis, MO, and Cabrini Green in Chicago, IL. Built in the years between 1952 and 1956 and consisted of 33 buildings of 11 story each (totaling about 3000 residential units), the Pruitt–Igoe project suffered immensely from social problems; and consequently, authorities demolished it in the years between 1972 and 1976. Importantly, research indicates that architectural design was not solely responsible for these developments' failure. Urban policies that "favored" and supported suburban living in the form of offering better educational systems and financial incentives for obtaining mortgages, have exacerbated these problems. Researchers observe these urban policies particularly in the American urban and suburban contexts [29,33]. Further, poor design, whether in a low-rise or a high-rise development, often results with lower residents' satisfaction. However, dissatisfaction in poorly designed high-rise environments could be greater because of their vertical orientation that conveys greater sense of confinement and distancing from the social life on the street [31,32].

At the other end of the spectrum, tall buildings have created private, luxury enclaves, or "mansions in the sky" for super wealthy people. These developments offer privacy, top security, restricted access, 24-h closed circuit camera system (CCTV) as well as a wide-range of services—analogous to those provided by luxury hotels. These towers often enjoy the closeness to urban amenities and services such as cinemas, theaters, markets, shopping malls, cafeterias, restaurants, pharmacies, public parks, and mass transit. In short, developers promote luxury high-rise living to enjoy the best of both worlds (urban and suburban) in one place. Nevertheless, these buildings often exclude lower-income communities.

The "mansions in the sky" phenomenon manifests differently in suburbia, where tall buildings are located on spacious land and function as autonomous neighborhoods with their guarded gates, exclusive services, and outdoor amenities, such as golf courses, parks, swimming pools, tennis courts, and marina. For example, Aventura, Florida, contains scattered clusters of "mansions in the sky", where amenities, services, and facilities are exclusive to tenants and their guests. Unfortunately, in both urban and suburban settings, these communities contribute to social and spatial fragmentations, thereby weakening the bonds of a civic society, and promoting fear and tension among socioeconomic classes [29,30].

Recent developments of ultra-luxury residential supertalls in New York City have reinforced the "mansions in the sky" phenomenon. New supertalls (e.g., One57 tower and 432 Park Avenue) are vividly exposing the new "social ladder" of the city by placing the richest people "physically" on the highest altitudes. This new socio-spatial polarization (vertical slums versus mansions in the sky) reinforces social and racial segregations, echoing Pierre Bourdieu's concept of "symbolic capital" [29].

Indeed, the "mansions in the sky" phenomenon symbolizes prestige, recognition, wealth, competition, and social class. Steven Holl, a leading U.S. architect [34], has denounced these developments because they create physical silos and isolate affluent residents from the rest of the city. In this regard, Jenna McKnight cites Aaron Betsky explaining, "Manhattan is being transformed into a Capitalist holy land with no space for the poor" [35]. He indicated that these tallest luxury residential towers epitomize the skyline's transformation from a symbol of collective economic prosperity to a symbol of greed, income inequality, and growth of individual wealth.

Indeed, New York City (NYC)'s ultra-luxury towers have drawn extensive criticism from the experts and the public alike. In her article titled "The Logic of Luxury: New York's New Super-Slender Towers", Carol Willis [36] explains that these towers create the following problems:

- Skew the housing market by raising price and decreasing affordability to the average residents,
- Strain the existing infrastructure,
- Cast undesirable shadows on street and public spaces,
- Absentee tenants of these buildings fail to support the local economy of businesses and social life of the neighborhood, and
- Tax avoidance by non-resident foreigners raises issues of fairness.

Opponents also voiced concerns that numerous purchasers of these residential units have paid from shadowy sources and have taken steps to hide their identities. In particular, overseas investors have been using illicit wealth to purchase properties secretly in luxury residential tall buildings located in “global” cities such as New York, London, and Hong Kong. In their article titled “Stream of Foreign Wealth Flows to Elite New York Real Estate” in *The New York Times*, Louis Story and Stephanie Saulfeb [37] elucidated that hidden ownership of expensive, luxury residences in Manhattan has become a commonplace. In 2008, building owners sold these units for \$5 million or more and shell companies that hid the buyers’ identities bought 39% of those residences. By 2014, the share of hidden buyers for luxury properties rose to 54%. On the Upper East Side, sales to shell companies have reached 42%. In 2014, 54% of sales over \$5 million in Manhattan were to shell companies. In uptown neighborhoods that have new construction, the share exceeds 60%, and in downtown Manhattan, building owners sold 63% of luxury residences to hidden buyers. Story and Saulfeb also bring several alarming stories highlighting these problems by explaining [37]:

On the 74th floor of the Time Warner Center, Condominium 74B was purchased in 2010 for \$15.65 million by a secretive entity called 25CC ST74B L.L.C. It traces to the family of Vitaly Malkin, a former Russian senator, and banker who was barred from entering Canada because of suspected connections to organized crime... Last fall, another shell company bought a condo down the hall for \$21.4 million from a Greek businessman named Dimitrios Contominas, who was arrested a year ago as part of a corruption sweep in Greece... A few floors down are three condos owned by another shell company, Columbus Skyline L.L.C., which belongs to the family of a Chinese businessman and contractor named Wang Wenliang. His construction company was found housing workers in New Jersey in hazardous, unsanitary conditions.

Completed in 2004, the Time Warner Center was New York’s trial run of the super luxury, super expensive condominiums. Located in a prestige spot, right at Columbus Circle and privileged with splendid views of the Central park, it is well suited to spark a global phenomenon that spilled over to Hong Kong (e.g., the Cullinan I & II (2008) and the Opus (2012) by Gehry Partners) and London (One Hyde Park (2009) by Rogers Stirk Harbour + Partners). More vividly, towers in the 57th street and its vicinity will likely gain a global status that rivals towers in other cities regarding height and price. For the sake of comparison, the heights of these towers are as follows [38]:

Cullinan I & II, Hong Kong	68 stories, 270 m/886 ft
Opus, Hong Kong	13 stories, 60 m/197 ft
One Hyde Park, London	14 stories, 50 m/162 ft
432 Park Avenue, NYC	85 stories, 426 m/1396 ft
111 West 57th, NYC	82 stories, 435 m/1428 ft
Central Park Tower, NYC	95 stories, 472 m/1550 ft

Towers in the “Billionaires’ Row” (referring to an area along 57th street and its vicinity) will certainly reinforce the view that New York is a global, cosmopolitan city, where its residents come from all over the world, and its “global” purchasers are not necessarily full-time residents. However, these factors may hurt the social sustainability of the neighborhoods. “Part-time residents” are likely to neither engage in the social life of the neighborhood nor economically benefit its retail, commercial, and grocery stores. In addition, learning that some neighbors purchase their flats using “unlawful” sources is likely to create mistrust and build social barriers among neighbors [36].

2.3. Human Scale

Humankind is the measure of all things, as Protagoras, the pre-Socratic Greek philosopher, suggested [39]. Observing human scale in the design of the built environment is essential for providing comfort to users. Because of their great heights, tall buildings, by default, violate human scale. Large cities with a conglomeration of soaring buildings face the challenge of providing a comfortable environment for pedestrians. They are likely to exhibit what Jacobs and Appleyard call “giantism” [39]. Developments of massive tall buildings cause passersby to feel small, dwarfed,

and irrelevant. These negative effects could be of less concern in tall structures such as the Eiffel Tower or Statue of Liberty because their “tallness” is less imposing. That is, these structures are often located in spacious areas (parks, water body, etc.) and hence viewers do not need to bend their heads or “break their necks” to see them. In addition, unlike ordinary tall buildings, these structures are exceptional because they serve symbolic purposes. They are emblematic objects rather than human habitats.

Jan Gehl has written extensively arguing that wonderful places feature three- to six-story buildings. He advocated low- to mid-rise environments as ideal places that can promote walkable and less car-dependent neighborhoods, and asserted that neighborhoods with shorter buildings are more successful urban places than those with taller buildings. He lamented that new skyscrapers, reaching unprecedented heights, are “eyesores” or at least less appealing than the low-slung Parisian urban design model. Overall, Gehl criticized steel-and-glass vertical urbanism for creating unpleasant, soulless, crowded, and inhumanly scaled environments [18,19].

Indeed, skyscrapers often shatter the urban scale by dwarfing nearby buildings, people, and public spaces. Pedestrians at the street level are often unable to connect visually with high-rise tenants, architecture, ornamentation, decorative art, and personalized details. For example, pedestrians cannot see the flowerpots in the upper-story windows, which bring a touch of humanity. Pedestrians also cannot completely see the high-rise building; instead, they see “urban canyons” that make them feel visually disoriented. Jane Jacobs argued in her seminal book *The Death and Life of Great American Cities* [20] that traditional low-rise neighborhoods with front porches and stoops facilitate the “eyes on the street” natural surveillance, and hence promote security and community spirit [40].

Similarly, Land H. Kendig and Bret C. Keast write in their book *Community Character: Principles for Design and Planning* (2010) (pp. 85–86 [41]): “At sixty feet (four to five stories), a building is ten times the height of a human; when a building reaches twenty stories, it is more than forty-four times human height. At this level, it is necessary to tilt one’s head back to see the skyline across the street”. Likewise, Jan Gehl elucidates that our “vertical” field of vision does not allow seeing upward unless we raise our heads. We also tend to bow our heads about 10 degrees when we walk, which makes it more difficult to perceive the high-rise environment. Horizontally, our cone of vision widens as we move away from tall buildings allowing us to see more of the skyline. Further, tall buildings not only dwarf human scale but also deprive streets of natural light, making them unattractive. Overall, a 1:1 ratio of street width to building height is desirable, and once we introduce tall buildings, they often alter this ratio drastically, creating urban canyon [39].

2.4. Placelessness and the Public Realm

Similarly, because of their massive size and great height, tall buildings have often contributed to the problems of placelessness. In central business districts (CBDs), tall buildings frequently evoke the image of a nerve-racking, workaholic business environment. In addition, in residential areas they convey the perception of living in crowded apartments that are more akin to cages than living spaces. Inhumanely high towers often shatter the human scale by dwarfing nearby public spaces and buildings, particularly those of a historic character [18]. People at the street level are unable to visually connect with them because they cannot see the whole building [20]. People often become disoriented and feel lost in their midst, as if they were engulfed by canyons of skyscrapers. Also, the tenants of high-rises tend to lose sight of the pedestrian and social life of the street. Conversely, pedestrians often cannot see the decorative art and personalizing details, such as flowerpots in the upper-story windows, which bring a touch of humanity to these types of living structures [39].

Speaking about Manhattan, Robert Freedman [42] contrasts high-rise with low-rise neighborhoods in the same island. He explains that in walk-up apartment neighborhoods in Manhattan, a resident or a passerby would immediately feel a warm welcome not found in the towering, elevator-skyscrapers neighborhoods that proliferate through most of Manhattan. Freedman argues that vernacular brick, wood, and stone low-rise neighborhoods are more humane than glittering, steel-and-glass high-rise neighborhoods. He prolifically explains [42]: “While walking, you have the sense that you ‘fit’. It’s not

unlike retrieving your jacket after having mistakenly slipped into someone else's that was several sizes too large. It just feels right".

Moshe Safdie has also commented that tall building developments often hurt the public realm. He explained that at the street level, tall buildings have replaced small mom-and-pop shops, commonly found in traditional neighborhoods, with large, blank-walled facades [43]. There are numerous tall building examples that support this view, including Westin Bonaventure Hotel, Los Angeles, CA, Hyatt Regency Hotel, Indianapolis, IN, the General Motors Renaissance Center, Detroit, MI, among others. Interestingly, it is not only tall building developments alter the feel and look of vernacular and traditional environments. New developments of shorter buildings could result with similar effects. However, the problem could be greater in tall buildings when they employ mega bases characterized by large and blank facades as well as lofty shafts as seen in the aforementioned examples.

According to Safdie, avant-garde architects strive to give new architectural forms or "objet" buildings that pay little attention to human and social dimensions. These buildings disturb the urban social life. Towers function as singular, autonomous structures—some are experienced as lonely sculptural objects in the cityscape. They often do not contribute to the public realm because they are self-contained, introverted, and privatized. Planning, zoning, and urban design guidelines have neither observed nor regulated the great socio-economic interdependence of towers and the city. Overall, architects and planners have failed to deploy a tall building as an effective building block of cities. "Only powerful concepts for how earth meets tower can begin to bring about an urbanism in which the public realm is continuous, truly public, and possesses the appropriate environmental conditions" [43].

Often, tall buildings require significant parking structures. Since it is costly to accommodate them underground, architects place them above ground, thereby taking away from the street social life and unstimulating the public realm. Their design is often insensible and damages the urban character. Parking garages above ground are a "street kill" because they disconnect social life of urban space, engender spatial disorders, and create "eyesores" in the city. Although this problem is not exclusive to tall buildings, it is most pronounced in this building typology because it requires greater parking spaces and larger parking garages.

Aesthetically, tall buildings often create contextual problems when placed near historic structures. As cities become denser and land values skyrocket, older historic structures are pressured to be demolished to make room for new taller buildings [43]. In their paper titled "Tall Versus Old? The Role of Historic Preservation in the Context of Rapid Urban Growth", Kate Ascher and Sabina Uffer illustrate this problem in three cities: New York City, Berlin, and Beijing. These cities face a challenge of accommodating new demand on space while preserving precious built heritage simultaneously. While Beijing has been engaged in razing large areas of its built heritage, New York City faces real estate pressure to make room for supertalls, and Berlin continues to debate which history is worth preserving [44].

In particular, New York City has been witnessing an increasing pace in building tall and supertalls. Most of these buildings have been replacing low-rise 19th-century structures, despite preservationists' objections, arguing that Midtown will soon reach "a tipping point in which the architectural mix of old and new is lost to a wash of sparkly glassy" (p. 108 [44]). This problem accelerates as demand on space increases, and developable lots are progressively scarce in Manhattan Island. Overall, historic preservation issues are often contentious and require an interdisciplinary team to make sound decisions.

At the larger scale, tall buildings have contributed to the problem of placelessness by creating spatial chaos. Their massive size and great height make it difficult to blend into neighborhoods. In central business districts (CBDs), tall buildings evoke the image of a nerve-racking, workaholic business environment. Also, in residential areas, they convey the perception of living in crowded apartments that are more akin to cages than living spaces [45]. The absence of an urban design vision that guides neighborhood and city developments have led to haphazard mushrooming of high-rises,

evoking visual disorder. What makes the problem worse is that individual architects have been using high-rises as an opportunity to display their artistic talents at a mega scale, contributing to conflicting architectural styles in the same neighborhood.

Importantly, current practices of tall buildings are making cities around the world look alike. For example, downtown Melbourne looks similar to that of Pudong, Shanghai, Miami, or Dubai. The common shortfall of these skyscrapers is that design has not paid attention to local tradition, geography, and climate. In particular, the steel-and-glass tower, which invaded cities, has made them look homogeneous and similar, ignoring local identity and culture. “High-rise buildings and modern architecture generally are homogenizing our cities in the same way that Starbucks and McDonald’s are homogenizing the dining culture... I think this is something we need to fight against... so many of the buildings are about a sculpted form. They could almost be a perfume bottle or a vase. That has become an international style” [46].

Recently, Richard Meier, one of America’s most respected architects, commented that New York is losing its character due to new disrespectful skyscrapers. He explained [47], “There’s a scale to New York as there is a scale to London, and that’s what makes the city great New York has a quality to it and you have to respect the context”. Particularly, when planners plant a tall building in an isolated manner, it has the potential to exert a negative omnipresent visual impact citywide. For example, the 209-m (686-ft) tall, 58-story Tour de Montparnasse in Paris has negatively affected the urban character of the city to the extent that the city banned tall buildings for years.

Adam Caruso echoes a similar concern by explaining that cities suffer from haphazard developments of tall buildings. The lack of effective urban design regulations and architectural guidelines has turned cities into a “free for all”, according to Caruso [48]. The key problem stems from the fact that the final say is for the one who pays for the project, the developer. Few countries, nevertheless, offer planners greater authorities and control over urban developments. For example, Germany gives the appointed city planners greater power to accept or reject a proposed building based on contextual fit, thereby preventing the emergence of chaotic urban design in the city [34].

2.5. Fire Incidences

Tall buildings are prone to massive losses of lives and valuable properties caused by fire. High-rise buildings present several unique challenges not found in traditional low-rise buildings, including greater difficulties for a firefighter to access a smoldering high-rise building, longer egress times and distances, complex evacuation strategies, and smoke movement and fire control. Typical dangers at a fire incidence involve flame, smoke, heat, toxic gases, flashover, and backdraft explosions. However, the multiple floors of a high-rise building create the cumulative effect of needing greater numbers of firefighters to travel great vertical distances on stairs to evacuate the building.

Therefore, it takes much longer time for fighters to rescue tenants of high-rises than that of low-rises. An extended time of burning fire increases chances that flame and smoke reach tenants, thereby causing greater death to people and damage to the building. A prolonged rescue time also makes firefighters exhausted, whom bodies get exceedingly hot due to closeness to fire and heavy protective gears and masks they wear. Further, in disastrous fires, sprinkler systems and fire elevators can malfunction [49].

Despite advances in fire codes, numerous high-rise buildings continue to be ill equipped. High-rises, particularly in the developing world, lack effective fire safety standards, fire prevention, and emergency action plans. In 2009, a fierce blaze engulfed the 31-story hotel and cultural center, which is part of the China Central Television’s headquarters (CCTV) in Beijing [50]. Designed by the renowned Dutch architect Rem Koolhaas, the fire happened few months before completion. It was difficult for firefighters to control fire because their equipment was incapable of fighting fire above the 20th floor. Luckily, the building was unoccupied; therefore, there were no casualties. However, a fire that burned an apartment building in Shanghai resulted in killing 48 and injuring 90 residents in 2010 [51]. In the same year, a fire hit Carlton Towers in Bangalore, a neighborhood in Delhi, India, which

led to the death of nine and the injury of 70 residents [52]. After the incidence, authorities investigated fire safety in the city and found that most high-rise buildings did not meet fire safety standards.

On the New Year's Eve of 2016, an intense fire engulfed the 63-story Address Hotel in Dubai, UAE [53]. An electrical short circuit caused a spark that triggered the blaze. Likewise, in 2015, the 86-story Torch building also in Dubai experienced a fire in its upper floors [54]. It took considerable time to evacuate this residential tower due to its exceptional height. In response to these fire incidences, Dubai has enacted new buildings' regulations requiring less flammable exterior cladding, as well as specific procedures for installation and maintenance. It also debuted jetpack-equipped firefighters in a bid to tackle skyscraper fires swiftly by avoiding traffic jams on the ground.

When construction completed, The Torch was the world's tallest residential tower. However, other residential supertalls completed recently have snatched that title. For example, global developers have built several new taller residential towers in Dubai, including the:

- 413-m (1356-ft), 101-story Princess Tower,
- 392-m (1287-ft), 88-story 23 Marina, and
- 380-m (1248-ft), 87-story Elite Residence.

In 2015, the New York City, however, snatched the world's tallest residential tower title from Dubai by building the 426 m (1396 ft), 85-story 432 Park Avenue, designed by Rafael Viñoly.

Most recently, in June 2017, a devastating fire hit the 24-story Grenfell Tower causing the death of nearly 80 and injury of additional dozens of its 600 residents as well as the destruction of the entire building, despite of the deployment of 40 fire engines and 200 firefighters—fire-fighting equipment did not reach beyond the 11th floor. Importantly, the building's owner has fitted combustible insulation boards (Celotex RS500 polyisocyanurate foam core (PIR)) behind the cladding during a recent refurbishment, which accelerated fire spread. Moreover, these boards have released cyanide gas that contributed to the deaths of some of the victims. Richard Hull, a leading professor of chemistry and fire science, commented, "Unlike ships, trains, or aircraft, where fire toxicity is regulated because it is accepted that escape may not be possible, the UK and most of Europe have no regulations on the toxicity of fire smoke from construction products, even though escape from a high-rise building may be equally impossible" [55]. As such, faulty materials as well as bribery have exacerbated the fire problem in this building.

Furthermore, building regulations when the tower was built in the 1970s did not require the installation of sprinkler systems (internal and external), which could have minimized fire damage. Until today, most cities do not require buildings with combustible cladding to integrate external sprinklers. Additionally, London's fire regulations require tower blocks to have merely one staircase. Certainly, a second staircase could have eased tenants' escape from the building.

Fires in high-rises threaten the lives of residents and firefighters alike. For example, high-rises incorporate tall shafts such as elevator shafts, smoke shafts, utility wire and plumbing shafts as well as package and mail and garbage chutes. Usually, safeguards such as railings, gypsum block walls, self-closing doors, and trap doors prevent occupants from falling into these vertical elements.

Nevertheless, a fire can destroy these safeguards, and in a dark or smoke-filled environment, firefighters can fall to their deaths in these shafts. Research has documented cases where fire has killed and injured firefighters in high-rise buildings such as the Empire State Building and 1 New York Plaza in New York City and One Meridian Plaza fire in Philadelphia. Further, during the fire, chunks of glass and metal of tall buildings may rain down on pedestrians on the ground [49].

Overall, security and safety systems are costly, and some are less effective. For example, helipads are costly and often helpless because helicopters take a considerable time to land, load people, and take off. They take a small number of a skyscraper's occupants at a time. Further, helicopter pilots are often extremely hesitant to land on a burning building, fearing that the helicopter may catch fire as blazes and smoke swiftly ascend.

Even if a pilot decides to take a risk and land on the rooftop, the rising heat and smoke from the fire may jostle and destabilize the helicopter, thereby complicating the landing process and preventing people from boarding the helicopter. Research revealed that if the World Trade Center rooftops had been accessible (the helipad fell into disuse), helicopters could not have landed because of the heat and smoke. Consequently, rarely used helipads may enhance the perception of safety; however, they have a limited role to play [56].

The helipad's integration in tall buildings limits skyline design. For example, the skyline of the City of Los Angeles, CA, has suffered from "flatness" dictated by local zoning codes that required that all buildings 75 ft (22 m) and taller integrate helipads in their roofs. The city enacted the law in 1974 after two deadly skyscraper fires in Brazil. However, authorities have canceled this law recently after discerning that helipads had been of little use.

Also, the helipad's problem in limiting design for rooftops was apparent in the one-kilometer-tall (3280-foot-tall) Jeddah Tower, currently under construction in Jeddah, Saudi Arabia. The architects proposed a protruding helipad near the top of the pointy tower. Nonetheless, helicopter pilots pointed out that they would not feel comfortable landing there because they feared tight space and potentially high winds could cause them to hit the tower. Consequently, the architects converted the proposed 7500-square-foot (697-square-meter) helipad to an outdoor terrace instead, known as the "sky terrace" that will overlook the Red Sea [56].

2.6. Terrorist Attacks

Large concentrations of people in confined spaces are increasingly considered targets for terrorist attacks. Tall buildings, by default, house large number of people as well as valuable assets, making them a potential target for terrorist acts. That is, tall buildings could be vulnerable to unanticipated tragic events. For example, no one predicted that Boeing 767 aircrafts would smash the World Trade Center (WTC) towers in New York City in 2001. In 1970, structural engineers designed the WTC towers to withstand the impact of a Boeing 707 plane—the largest commercial plane at that time. However, the Boeing 767 planes used in the September 11 attack were larger and carried 20,000 gallons of jet fuel.

Another example that illustrates how tall buildings could be a target for a criminal act is the Alfred P. Murrah Federal Building in Oklahoma City, OK, where a bomb in a rented truck exploded outside the building, causing considerable damage in 1995. Earlier, in 1945, B-25 two-engine bomber crashed into the Empire State Building as the pilot lost track during a heavy fog. Flaming gasoline from the 1400-gallon tanks burned to death 14 and injured 26 tenants [57].

2.7. Window Cleaning, Repair, and Maintenance

Daily activities carried out to repair tall buildings and to clean their windows threatens the lives of workers. People often take the issue of window cleaning of skyscrapers lightly; however, it continues to be a frequent cause of the death of workers. Cleaning crews perform tasks manually by descending the height of the building from the roof to the ground floor while hanging on ropes and carrying water buckets and cleaning tools. Workers go down floor-by-floor, but some get dizzy and fall off while others bounce into walls and windows because of forceful wind.

Cleaning mechanical systems may fail. For example, two cleaning workers were stranded in their scaffold as one of its two ropes slacked while cleaning the exterior windows of the recently completed One World Trade Center. The scaffold flipped over almost vertically, and workers waited in place for nearly two hours for rescue [58]. By using a diamond saw, the Fire Department of the City of New York (FDNY) cut through the glass panel from inside the building and rescued them. Though successful, the process was risky since cutting a hole in the window at a higher altitude could have created a powerful wind tunnel.

Nevertheless, cleaning skyscrapers' windows is a daunting task, particularly for larger buildings. For example, it takes 36 window cleaners four months to clean the 26,000 windows of Burj Khalifa [59]. Importantly, there are issues of labor abuse since most of these workers are immigrants and employers

deprive them of their social rights, safety, security, and health benefits. For example, most of the window cleaners in Hong Kong are immigrants from countries of Philippines and Indonesia. In New York City, the majority of window cleaners are immigrants from South America [59].

Unfortunately, we are technologically far from having robots replacing cleaning workers. Machines cannot clean windows as well as cleaning workers do. Unmanned cleaning machines tend to leave dirt, stances, spots, and gray areas around the rim of the window, for example. These machines also cannot reach building corners well, and they have difficulties to work with facades that feature treatments and articulations, recessed windows, metallic decorations, and cantilevered elements. We tend to underestimate the importance of having a clean and clear glass. Nevertheless, buildings' tenants who pay a high price for views do value clean windows.

What makes the problem worse is that architects increasingly design complex shapes for skyscrapers, making it harder for a machine to do the job. A robot will not be able to maneuver complex shapes to reach each facet of the building. Also, buildings' owners are clinging on traditional rope-and-scaffold systems because they need them for purposes other than cleaning windows, including maintenance and repair, for example for repairing facades, balconies, and broken windows. Regardless, it is pathetic that we can develop technology to put a man or women on the moon, but we are incapable or unwilling to develop technology that saves workers' lives, window cleaners, and construction crews. It is sad that skyscraper design does not pay adequate attention to these problems. Architects continue to focus on inventing new forms and shapes, not on saving lives. The window-washing problem should be the first not the last to address.

Further, window cracking and breaking are common problems in supertall buildings. Indeed, glass ages and weakens over time and any deficiencies in manufacturing or installation could lead to cracks or breakups under wind pressure. For example, Willis Tower (formerly Sears Tower) in Chicago has experienced several incidences where under forceful wind some windows in the upper floors were shattered. On 22 February 1998, winds gusting to 56 miles an hour broke and cracked 90 panes of the Willis Tower [60]. Debris fell on sidewalks, damaged properties, and hurt pedestrians. For safety considerations, police blocked streets and rerouted traffic, causing inconveniences and traffic congestion in adjacent neighborhoods.

2.8. Construction Workers

Constructing tall buildings, particularly supertall, may entail the death and injury of construction workers. Unfortunately, construction activities continue to rely on labors who perform tasks manually. For example, façade assembly and exterior cladding rely on labors so that they manually grab panels from cranes and fixate them in assigned places. Construction workers repeat this process for each panel individually until the façade is complete. The process is tedious as panels are in thousands; for example, Burj Khalifa contains 26,000 glass panels [59]. The assemblage task is most challenging in upper floors where the wind becomes more powerful and in the process, some workers fall and die. Tragic cases also happen during similar tasks, for example assembling structural systems.

Construction workers bear a risk in building skyscrapers. A recent online article by the *For Construction Pros* reports the following incidences in constructing skyscrapers [61]: five deaths for the Empire State Building, 60 deaths for the 1970s World Trade Center, five deaths for the Sears Tower; and six deaths for the Las Vegas's CityCenter project. Also, in 2016, a construction worker fell to his death from the 53rd floor of the Wilshire Grand tower in downtown Los Angeles [62], and in 2017, in Manhattan, two workers fell about 35 feet from an external elevator shaft, killing one and injuring the other. Further in Manhattan and in the same year, a construction worker fell from the 29th floor to his death [63].

Regrettably, automating the entire construction process of skyscrapers is still far from reality. Overall, specialized labors and high precision work are essential in all construction activities of skyscrapers [64]. As architects design more complex forms and shapes of buildings (including tall ones), construction workers face greater risks. However, it is interesting to note that the greater death of construction workers occur in constructing canals, tunnels, and railroads not buildings [61].

2.9. People's Choice

Recent massive high-rise developments in China teach us new sustainability lessons. The Chinese government has enormously promoted constructing high-rise cities to house new massive urban population flocking from rural areas. However, Chinese people have largely shunned these developments because they disliked the design, layout, architectural styles, schools, and amenities. Certainly, these cities were developed in a rushed manner, attempting to house hundreds of thousands of people in a few years, and consequently, city planners disengaged residents from the design process and deprived them from voicing their preferences. The design process did not take into considerations that many of the intended inhabitants were villagers who were accustomed to low-rise living, not high-rise living [65].

Ordos Kangbashi in China is one of several new high-rise cities sitting almost vacant because of these reasons. Although Ordos Kangbashi offers beautiful architecture, attractive plazas, and state-of-the-art recreational spaces, this stillborn city lacks the essential ingredients of success including affordability, socio-economic vitality, and employment opportunities [65]. Further, Ordos Kangbashi's location is detrimental for being remote from any settlements. It is located in the Inner Mongolia's vast steppe that features a harsh climate and lacks basic life essentials such as water and vegetation. Consequently, while planners have designed this new city to house over a million of inhabitants, barely a few thousands ever settled.

Chinese people have nicknamed these cities "modern ghost cities" because they evoke an eerie sensation promoted by silent streets, vacant high-rises, empty parks, and dead public spaces. In turn, this prevailing negative image has further discouraged people from considering moving into these new high-rise cities [65]. This local phenomenon has promoted global consciousness and a negative image about high-rise developments.

2.10. Health and Well-Being

Many studies found that tall buildings' tenants experience emotional stress and other negative psychological conditions. Research indicates that undesirable social interaction among tenants because of sharing floors and amenities tends to create stress and tensions [31]. In addition, the greater degree of sharing space and utilities exists, the greater level of stress was developed. Further, high density of a building population, poor design and layout, high traffic of people in and out, and the lack of outdoor recreational and social spaces are likely to exacerbate these problems. In particular, tall buildings of poor neighborhoods suffer from high concentration of population, overcrowding, little outdoor and social spaces, and feature a high degree of space and utility sharing. In contrast, tenants of high-end high-rises may suffer from isolation and loneliness [31].

3. Economic Dimension

Skyscrapers are costly buildings (Table 1). Their costs are greater than that of low-rise buildings holding the same square footage because they need stronger foundation and structural systems to withstand natural forces of wind, gravity, and earthquakes, and to resist severe weather conditions such as hurricanes, tornados, and typhoons [59] (Table 2). As such, tall buildings demand enormous amounts of steel and concrete—for example, the construction of One World Trade Center required 50 thousand tons of steel and 182 thousand cubic yards of concrete [66].

Table 1. Skyscrapers are costly buildings [59].

#	Skyscraper	Billions
1	Abraj Al Bait	\$15.49
2	Marina Bay Sands	\$5.98
3	One World Trade Center	\$3.92
4	Taipei 101	\$2.26
5	Princess Tower	\$2.24
6	Antilia	\$2.17
7	Trump Taj Mahal	\$2.00
8	Bank of China Tower	\$1.81
9	Petronas Twin Towers	\$1.65
10	Burj Khalifa	\$1.63

Table 2. Super-tall buildings' embedded foundation depth [66].

Project	H (m)	D (m)	H/D
Burj Khalifa	828	15	55.2
Shanghai WFC	492	21.35	23.0
Tianjin Goldin Finance117	587	25.85	22.7
Guangzhou West Tower	432	20	21.6
Taipei 101	448	22.3	20.1
Hong Kong IFC	484	25.5	19.0
Shanghai Tower	580	31.4	18.4

H: Structure height, D: Embedded depth of foundation.

Skyscrapers also require expensive vertical transportation such as elevators and escalators, as well as enormous energy to pump water to upper floors. They suffer from diseconomies of vertical construction systems (e.g., taller cranes, jumping cranes, “kangaroo cranes”, jumping boards, and hydraulic pistols). Pumping concrete to higher floors demands powerful pumps and special concrete that can travel long distances without stiffening too soon, resulting otherwise in clogging hoses. Skyscrapers also feature a lower “net-to-gross” ratio, referring to the net usable space in the building—about 70% for high-rise buildings comparing to more than 80% for low-rise buildings [39]. Furthermore, they consume substantial energy, often generated from fossil fuel sources. Alternatively, renewable energy means, such as photovoltaic cells, continue to be largely inefficient.

3.1. Premium for Height

When a building becomes taller, the “premium for height” principle applies due to increased lateral wind and gravity forces. Consequently, demands on the structural system dramatically rise, increasing total material consumption. To ensure structural stability, tall buildings use dampers, (i.e., sophisticated, gigantic pendulum-like counterweights—weighing anywhere from 300 to 800 tons) and other movement-tempering devices. Structural engineers employ dampers to mitigate vibration impacts, caused by wind, storms, and earthquakes, by pulling a building’s mass in the opposite direction of the prevailing forces. Tall buildings face greater structural-stability risks than low-rise buildings caused by “relatively long fundamental vibration period, significant mass participation, and lateral response in higher modes of vibration, and a relatively slender profile” (p. v [67]). Simply, the sway problem becomes greater as we build taller. For example, for a 300-m (984-ft) tall tower:

1. A 10-mile-per-hour wind may move the tower two inches.
2. A 50-mile-per-hour wind (which occurs about once a year) could move the tower about half a foot.
3. A 100-mile-per-hour wind (which happens about once every 50 years) could move the tower as much as two feet [59].

Overcoming sway problem in slender towers is acute, and therefore, an engineering solution is exceedingly costly. For example, the 426-m (1396-ft), 85-story 432 Park Avenue in New York City integrates two tuned mass dampers. A typical system can take up thousands of square feet of space and use a double-height ceiling.

Further, skyscrapers require costly mechanical, electrical, and plumbing (MEP) systems to cool and heat interior spaces and to supply water. Skyscrapers feature glass envelopes to allow in greatest natural light. However, heating and cooling interior spaces of these buildings are costly particularly in places that experience extreme weather conditions, for example, hot summer in Dubai and cold winter in Moscow. MPE systems also occupy considerable valuable space. Typically, a dedicated MPE floor is required for every 20–30 floors [59].

3.2. Vertical Transportation

Skyscrapers need a great number of elevators simply because they are the prime mode of transportation—people usually are unwilling to walk up more than a few floors (Table 3). Second, people do not tolerate long waits. Therefore, engineers compute the needed number of elevators so that tenants do not wait for elevators more than a certain number of seconds—about 30 s for commercial office buildings and 45 s for residential ones [59].

Table 3. Number of elevators in major tall buildings [59].

#	Building Name	# of Elevators
1	Shanghai Tower	106
2	Willis Tower	104
3	Makkah Clock Royal Tower	94
4	Shanghai World Financial Center	91
5	Guangzhou CTF Finance Centre	86
6	Wuhan Greenland Center	84
7	International Commerce Centre	83
8	Ping An Finance Center	80
9	Petronas Towers	78
10	Taipei 101	61

However, if one of the elevators malfunctions, overcrowding develops quickly at the lobby. As such, it is important to consider this issue early on in the design process. Further, “With the introduction of cloud technology and external data storage, some office occupiers no longer require extensive cabinet storage space or even bulky server rooms, creating ever more space for occupiers themselves. This puts pressure on an elevator system that may have been designed for lower capacities” (p. 30 [68]).

Skyscrapers also need multiple types of elevators (e.g., local, express, service, freight, firefighters). As skyscrapers increasingly host multiple functions (e.g., residential, office, hotel), architects need to incorporate more elevators. Therefore, elevators add not only significant costs to the building but also consume significant useable space. Further, elevators’ shafts need special construction techniques to ensure their perfect vertical alignment. Also, vertical circulation systems such as stairways and escalators take up additional usable spaces.

Post construction, elevators require close monitoring and maintenance. As such, building managers need to hire resident engineers who should be experienced in mechanical and electrical systems, IT networks, software, and programing languages (p. 30 [68]). Furthermore, elevators may cause ear trauma (called “barotrauma” or “perilymph fistula”) due to the pressure difference arising from the change in altitude as passengers ascend and descend a great number of floors with high speed.

Post 9/11, authorities have placed more stringent requirements on all vertical transportations. For example, new codes require stairways to be wider so that they can accommodate two flows of people—a flow of tenants going down escaping the building and a flow of firefighters going up to rescue tenants. Overall, as we are building higher, architects need to incorporate advanced elevator systems to allow tenants reach their destinations swiftly while ensuring their comfort and safety [59].

3.3. Vanity Height

In addition to “wasting” spaces to house elevators, mechanical, structural, and damping systems, skyscrapers may “waste” additional spaces for merely boosting height. The CTBUH has coined “*vanity height*” term to refer to the wasted space between a skyscraper’s highest occupiable floor and its architectural top [69]. As such, “*vanity ratio*” equals to “*vanity height*” divided by the architectural height of the building.

A CTBUH’s study reveals that skyscrapers increasingly feature a greater vanity ratio. The average vanity ratio in the UAE is 19%, making it the nation with “vainest” tall buildings. The Burj Khalifa’s vanity height is 244 m (800 ft), which qualifies to be a skyscraper on its own. Burj Al Arab in Dubai, UAE, has a 39% ratio (124 m: 321 m), (407 ft: 1053 ft)—the greatest “*vanity ratio*” among completed supertalls (Table 4).

Table 4. World’s tallest vanity height as of July 2013 [69].

#	Building Name	Architectural Top		Vanity Height		Vanity Ratio
		Meters	Feet	Meters	Feet	
1	Burj Khalifa	828	2717	244	801	29%
2	Zifeng Tower	450	1476	133	436	30%
3	Bank of America Tower	366	1201	131	430	36%
4	Burj Al Arab	321	1053	124	407	39%
5	Emirates Tower One	355	1165	113	371	32%
6	New York Times Tower	319	1047	99	325	31%
7	Emirates Tower Two	309	1014	97	318	31%
8	Rose Rayhaan by Rotana	333	1093	96	315	29%
9	The Pinnacle	360	1181	95	312	27%
10	Minsheng	331	1086	94	308	28%

3.4. Speculative Investment

Financially, tall building developments could be a risky investment where developers bet on economic growth and overlook economic recession that results in massive vacancies in these buildings. Often, the market experiences a housing bubble when extortionate profit potential triggers a construction boom that exceeds demand and affordability; and when the economy slows down, the housing bubble burst.

A similar situation happens in the office space sector. Office buildings suffer from vacancies simply because of the cost of running the building or because of an outdated look and functionality. Further, the fluctuating nature of financial and lending systems may result in delaying, discontinuing, or canceling the construction of tall buildings. For example, because of the recent financial crisis, the developer of the Spire Tower in Chicago canceled the project after working on the foundation. Consequently, the site remains disserted, creating an eyesore in the community.

Further, demographic changes and shifts in lifestyles could challenge the sustainability promise of tall buildings. For example, recent ultra-luxury tall building developments in the U.S. have been betting on the exceedingly wealthy people who form a small proportion of the world population. Owners of these buildings sell housing units for tens of millions of dollars. However, developers are bearing the risk of overshooting the mark. Other residential tall building developments have been betting on the millennials and downsizing retirees. Nevertheless, these developments may face high vacancies when the millennials flock to suburbs to start families and retirees’ population declines [59].

3.5. Building Construction

Further, design and construction mistakes could have a rippling effect that would result in prolonging the period of construction, thereby incurring additional costs. For example, the John Hancock Center in Chicago faced construction problems. After building the foundation, which consisted of 57 caissons (8-foot-thick (2.4-m-thick) concrete columns), workers discovered that one of the caissons had shifted 0.9 in (2.3 cm). Specialized workers had to perform sonic tests to detect weak spots. They found that the contractors, to save time and money, removed machinery while the concrete was still settling. Chicago's fragile soil had seeped into concrete, causing the shift. Correcting this problem set the project back several months and increased construction costs [59].

While under construction, the 10,344 windows of the 60-story 200 Clarendon (alternative names include John Hancock Tower and Hancock Place) in Boston, MA, were cracked and replaced with temporary sheets of plywood and later with permanent thick glass—a process that delayed opening the building for 4–5 years [59]. The original façade consisted of double-layered reflective glass with a thin strip of lead sandwiched between the two layers. The lead layer had begun to develop fatigue and to crack. Further, because the lead layer glues so tightly to the glass, it transferred cracks into the reflective chrome coating on the glass, eventually causing the glass to crack.

Further, this slab tower had a wind-sway problem resulting from its exceedingly narrow profile. Structural engineers failed to see this problem during the design process and had to retrofit the tower post construction by adding 1650 tons of steel beams to stiffen the vulnerable narrow side at the cost of \$5 million [59]. To provide greater stability to the building, structural engineers also integrated two 300-ton weights tuned mass dampers onto the 58th floor. Moreover, the excavation for the tower's foundation caused stability problems for the nearby buildings including the Trinity Church and the Copley Plaza Hotel [59].

Severe weather conditions and natural hazard events also impact and delay construction process of tall buildings, adding substantial costs. For example, on 29 October 2012, when One World Trade Center was under construction, Hurricane Sandy made a landfall on the East Coast and hit the New York City including the Ground Zero Site (the site of the One World Trade Center). Rainwater has soaked the unfinished structure and filled the 16-acre site with water with varying depth of 10–140 feet, totaling about 125 million gallons of water. Construction workers had to drain water from the entire building as well as the site [64]. Similarly, when Shanghai Tower was under construction, a typhoon hit the tower, causing damage and delay [65].

3.6. Unfinished Tall Buildings

Noticeably, there are incidences where the construction of tall buildings started but was not completed due to financial hurdles, political pressure, and cultural opposition. Indeed, financing a skyscraper is not a simple task. Many ambitious tall projects start during economic booms, and when economic busts occur, these buildings suffer. A recent CTBUH research mapped out 50 projects of 150-m or taller buildings that were not completed. Table 5 lists the unfinished 20 tallest buildings worldwide and displays the time of starting and halting construction.

Table 5. Tallest unfinished buildings, based on CTBUH data, 2014 [70].

#	Building	General Information			Construction Status								
		Heights		City	Date Started	Date Ended	Foundation Started	Foundation Completed	Pilings Started	Pilings Completed	Excavation Started	Framing Started	# of Floors Built
1	Nakheel Tower	1000+ m	3280+ ft	Dubai	2008	2009			X				
2	India Tower	700 m	2296 ft	Mumbai	2010	2011	X						
3	Russia Tower	612 m	2008 ft	Moscow	2008	2008							X
4	Chicago Spire	610 m	2000 ft	Chicago	2007	2008	X						
5	Doha Convention Center Tower	551 m	1808 ft	Doha	2007	2012			X				
6	Burj Al Alam	510 m	1673 ft	Dubai	2009	2009					X		
7	Palace of Soviets	495 m	1624 ft	Moscow	1937	1941							X
8	Lam Tara Tower I	454 m	1490 ft	Dubai	2008	2010						X	
9	Lighthouse Tower	402 m	1319 ft	Dubai	2009	2009					X		
10	Fairwell International	397 m	1302 ft	Xiamen	1997	1997	X						
11	Metropolitan Life North Annex *	390 m	1280 ft	New York City	1931	1933							31
12	Lam Tara Tower	384 m	1260 ft	Dubai	2008	2010					X		
13	Post and Telecom Building	364 m	1193 ft	Xiamen	1996	1997		X					
14	Sino Steel International Plaza T2	358 m	1175 ft	Tianjin	2009	2010	X						
15	Faros de Panama Torre Centra I	346 m	1135 ft	Panama City	2008	2008	X						
16	Torre Planetarium I	343 m	1125 ft	Panama City	2008	2008	X						
17	Skycity	335 m	1099 ft	Mandaluyong	1997	1997					X		
18	Waterview Tower **	319 m	1047 ft	Chicago	2006	2008							26
19	City Hall and Duma	308 m	1012 ft	Moscow	2006	2008	X						
20	Torre Planetarium II	305 m	1001 ft	Panama City	2008	2008	X						

* Originally planned to be a 100-story building. However, in 1933 construction was halted at the 29th floor, and then resume in 1933, resulting in the existing 31-story Metropolitan Life North Building; ** Waterview Tower (renamed One Eleven) was completed in 2014. CTBUH included it in the 20-unfinished list because researchers gathered the data prior to its completion.

4. Environmental Dimension

Skyscrapers suffer from a large carbon footprint observed in their construction, operation, maintenance, and demolition at the end of their life cycles. They exert significant demand on infrastructure and transportation systems, creating overcrowding and traffic congestions. In some projects, for example, Brickell City Center in Miami, FL, the developer had to relocate existing infrastructure (e.g., water, sewer, and drainage utilities) to accommodate buildings' footprints, deep foundations, basements, and parking garages. Tall buildings also could negatively affect the neighborhood character and the city skyline.

Further, tall buildings exert an adverse effect on the microclimate due to wind funneling and turbulence around their bases, causing discomfort to pedestrians. They cast a shadow on nearby buildings, streets, parks, and open spaces, and they may obstruct views, reduce access to natural light, and prevent natural ventilation. Further, we have little experience in demolishing skyscrapers. "It is an interesting fact that, apart from World Trade Center in 2001, no building over 200 meters has ever been demolished" (p. 28 [68]). We will need to develop the technical expertise to enable deconstructing skyscrapers at the end of their life cycles with minimal environmental impact.

4.1. Energy and Carbon Emission

Skyscrapers' construction and operation require great energy and generate significant amounts of carbon emission and air pollution that contribute to global warming. High-rises consume lots of steel and cement—manufacturing these materials requires lots of energy and generates large amounts of carbon dioxide. Also, tall buildings' construction requires great energy and generates considerable carbon dioxide because of operating heavy machinery and equipment such as powerful cranes and pumps (e.g., pumping water and concrete to upper floors) and dump trucks. Transporting building materials from far distances (sometimes across the globe) also consumes energy and produces immense carbon dioxide [71,72].

Alternative eco-friendly materials (e.g., local wood, earth, clay, or gravel that have smaller ecological footprint than steel and concrete) are not suitable for constructing skyscrapers. However, recently, architects and structural engineers have been experimenting with using compressed wood for constructing tall buildings. Further, skyscrapers consume great energy and generate significant greenhouse emission resulting from running mega electrical, mechanical, lighting, and security systems. Architects have built skyscrapers with poor thermal performance and without natural ventilation, meaning that buildings' owners need to continuously heat and cool indoor spaces (in the winter and summer respectively) to make sure that tenants have comfortable indoor environments. As such, the energy needed to heat and cool these skyscrapers is not only costly but also hurts the environment by generating massive carbon dioxide [73–75].

Further, in many cases, tall building developments are located away from mass transit systems. As a result, tenants drive automobiles to commute between home and work, which results in using greater energy and generating greater carbon emission. That is, once skyscraper's tenants and visitors use the private automobile exclusively, whatever we do to make a vertical development "sustainable" is "like putting lipstick on a pig", according to Donald Elliott (p. 39 [76]). This regionally "detached" skyscraper does nothing to reduce carbon emissions, energy consumption and the time wasted in long commutes, undoing any gains made by "green" features such as photovoltaic panels and wind turbines.

4.2. Urban Heat Island Effect

The urban heat island (UHI) effect refers to an increase in temperature in dense inner city locations over the fringe of the same city. The concentration of heat in urban areas or UHI could increase temperature by 10–12 Fahrenheit degrees, according to Rudi Scheuermann (p. 106 [77]). The temperature increase is a result of the massive concentration of urban areas—made up of heat-retaining materials, such as asphalt, concrete, steel, bricks, and impervious ground and roof surfaces, which collectively act as a huge thermal

mass that absorbs solar radiation during the day and discharges it in the form of long-wave heat radiation during the night.

Therefore, dark surfaces that absorb heat from the sun, a lack of greenery, and waste heat from industry and vehicles lead to higher temperatures in cities than that in the rural areas around them. Motorized traffic in particular “contributes up to a third of the anthropogenic heat produced in urban areas” (p. 530 [78]). In the context of high-rise buildings, “The height of the heat island is three to five times of the average building height” (p. 305 [79]). As such, a concentration of tall buildings increases the city’s thermal mass; and consequently, it increases the UHI effect. In a nutshell, as cities grow denser and accommodate taller buildings and greater auto traffic, UHI intensity will increase significantly.

Overall, when extreme heat occurs, high-rise cities have more trouble cooling off than other places do, creating a greater demand for energy to cool spaces. Also, heat waves aggravate both indoor and outdoor thermal discomfort and negatively affect people’s health when the human body cannot cool off at night. UHI also decreases air and water quality by increasing the production of pollutants. Recent research indicates, “... both nocturnal and diurnal urban effects have an important impact on the primary and secondary regional pollutants, more specifically the ozone and the nitrogen oxide (NO_x)” (p. 1743 [51]). Warmer polluted air can increase people’s risk to vector-borne and infectious diseases such as West Nile virus and Lyme disease. Collectively, scholars have indicated that UHI contributes to climate change and global warming [80].

4.3. Wind

Urbanization weakens natural ventilation because buildings block breezes coming from nearby natural fields such as ocean, sea, lakes, forests, farms, and mountains [81]. Given their greater heights and larger masses, tall buildings impact natural wind directions and patterns by increasing the distance of wind shadow and minimizing the air flow in the leeward direction, i.e., behind buildings. Therefore, in polluted urban environments, decreased airflow augments stagnation and accumulation of air pollution.

At the street level, tall buildings create a wind tunnel effect that increases wind speed and turbulence, which discomforts pedestrians. Strong airflow that occurs around tall buildings creates eddies, loops of dust and air pollution, thereby disturbing and discomforting street activities. Wind acceleration manifests in open areas, including plazas, passages, entrances, corners, and spaces between buildings [81].

4.4. Sea-Level Rise

Geographically, numerous high-rise cities stand along shorelines (e.g., Hong Kong, Guangzhou, Shanghai, Tokyo, New York City, Miami, San Francisco, Sydney, Melbourne, etc.) and are—to a greater or lesser degree—threatened by rising seas. Sea levels could rise three, five, or six feet by the end of the twenty-first century, according to the Intergovernmental Panel on Climate Change, the United States Army Corps of Engineers, and the National Oceanic and Atmospheric Administration, respectively. Some geologists consider these estimates to be lower than what will happen, contemplating the possibility of a ten- to thirty-foot rise [71].

High-rise cities concentrate a larger number of people, asset, and infrastructure that make flooding more destructive and costly. Implementing physical measures to mitigate flood in dense cities—such as building walls—is challenging and could interfere with existing infrastructure and weaken the connectivity between sidewalks and buildings’ ground floors, thereby creating pedestrian-unfriendly environments [82].

4.5. Geological Considerations

The geological structure of a place poses several implications for constructing tall. For example, when tall buildings stand on a flimsy soil, their collective weight may result in a gradual sinking of the place. Shanghai offers an illustrative example. The city has inherently soft soil because of

its geographical position at the mouth of the Yangtze River basin, and groundwater accounts for nearly 70% of land subsidence. Unfortunately, the heavy weight of new colossal skyscrapers coupled with massive depletion of groundwater has caused large areas to sink. The sinking problem will be worse when the sea-level rise occurs—the sea level close to Shanghai is expected to increase by five centimeters (two inches) by 2050 [71].

While it is safest to anchor a skyscraper's foundation over a bedrock (a geological layer of solid rock), it is not always easily accessible. In some cities, the bedrock is so deep that it would be too expensive to reach it. Other cities have a combination of swampy soil and deep bedrock. Steadyng skyscrapers in these places is costly because they require a staggering feat of structural engineering. Otherwise, skyscrapers could collapse.

Chicago, the birthplace of skyscrapers, offers a prime example of a swampy place with a bedrock (called dolomite) as deep as 85 feet. The 1889 Auditorium Building (now Roosevelt University) provides an early example where Dankmar Adler and Louis Sullivan invented a foundation system that consisted of isolated, giant pyramidal piers—measuring more than 12 feet tall and comprising layers of wood, steel, concrete, and stone—to distribute the structural load at several points across the Auditorium Building's base. Unfortunately, the building faced a “differential settlement” problem where heavier parts of the building settled deeper than the lighter parts [71].

Later, Burnham and Root's 1891 Monadnock Building used a ‘grillage’ foundation, a raft system with pyramid-shaped feet that make the building float on the clay. A few years later, engineering used the caisson system that consists of steel pipes filled with concrete that reach the bedrock. Structural engineers applied this system for Adler and Sullivan's Stock Exchange Building. Since then, engineers have refined the caisson system, and they use it today for skyscrapers in swampy places [59].

As mentioned earlier, Shanghai has challenging soil and seismic conditions defined in the China Building Code as type IV, which approaches the Class F classification in the IBC code [83]. As such, engineers have to devise special design for towers' foundations. For example, for Shanghai World Financial Center (SWFC) engineers employed a foundation made of more than two hundred concrete-filled steel pipe friction piles and a thick reinforced-concrete mat that transfers loads of building's column to the piles. Construction workers had to drive friction piles to a depth of 78 m (256 ft) from the ground surface. Similarly, engineers designed a special foundation system for Shanghai Tower. Its foundation consists of 947 bore piles (52–56 m long (171–184 ft)) of one-meter diameter and a six-meter-deep mat. Undoubtedly, transporting long pipe piles and bore piles to construction sites is a daunting task [83].

Another remarkable example is the original World Trade Center complex in New York City, which needed constructing a sizable underground slurry wall (known as the “bathtub”) that surrounded the entire 16-acre site to protect it from floods caused by the adjacent Hudson River. Built in the 1960s, the nearly one-meter-thick wall was made of reinforced concrete. Although survived post the collapse of the towers because of 9/11 terrorist attacks, the slurry wall became weak. In the process of redeveloping the site, engineers reinforced the existing 20-m-deep (57 ft) slurry wall by adding a linear wall that ties with the new buildings' foundations [84].

Similarly, given Miami's high water table, building basements have been structurally difficult, even prohibited in the city. Recently, the recent Brickell City Center development had to use innovative engineering solutions to accommodate a 1600-space underground parking garage. “To build the garage, teams used a newly developed deep-soil mixing technique to place a temporary cement soil mix plug and perimeter permanent sheet piling, creating a dry hole for construction. Deep Soil Mixing technology consists of an in-ground blending of native soils with an injected cement grout mixture, which serves to stabilize the soil to facilitate excavation during construction activities” (p. 95 [85]).

Other skyscrapers stand on sandy soil. For example, the 1000-m Jeddah Tower in Jeddah, Saudi Arabia (under construction) faced challenging sandy soil conditions that required innovative solutions, full-scale foundation testing, and sophisticated computer modeling. The tower's foundation consists of 226 1.5-m-diameter and 44 1.8-m-diameter cast-in-place piles (with a spacing 2.5 times pile

diameter) connected to a reinforced concrete raft. Corresponding with transferred loads, the raft's thickness varies: thickness at the wings is 4.5 m, which it increases to 5 m at the center. Similarly, the pile's depth varies: it is 45 m deep in the wings, 105 m at the center of the tower, and 65 m and 85 m in between [86].

Certainly, fragile soil worsens the issue of buildings' settlement. The 197-m (645-ft)-tall, 58-story Millennium Tower in San Francisco, CA has recently faced this problem. This residential tower has sunk 16 in (40 cm) since its completion in 2009. Also, the tower had already sunk more than eight inches (20 cm) by the time its construction was completed, totaling 24 in (60 cm).

Upon examining the problem, the building's owner blamed structural engineers for a deficient foundation. However, engineers argued that the sinking problem was caused by the construction activities of a new massive transport hub taking place next door. Dangerously, the tower is leaning six inches toward a neighboring skyscraper. Overall, buildings' foundations in the Bay Area do not reach the bedrock [87]. What makes the problem worse is that the city lies within an earthquake-prone zone and faces landslides issue.

4.6. Bird Collision

Bird-glass collisions are an unfortunate side effect of tall building developments throughout the world. Billions of birds perish from collisions with glass yearly, making it the second largest human-made hazard to birds after habitat loss. The U.S. alone is responsible for up to a billion birds yearly [88]. To make matters worse, countless victim birds belong to already declining population species, including Canada Warbler (*Cardellina Canadensis*), Golden-winged Warbler (*Vermivora chrysoptera*), Kentucky Warbler (*Geothlypis Formosa*), Painted Bunting (*Passerina ciris*), Wood Thrush (*Hylocichla mustelina*) and Worm-eating Warbler (*Helmitheros vermivorum*) [88,89].

Clear and reflective glass result in killing birds because birds perceive clear glass as an unobstructed passageway; and consequently, they attempt to fly through. On the other hand, reflective glass reflects the sky, clouds, and nearby vegetation reproducing a perceived habitat familiar and attractive to birds. Since the majority of modern tall buildings are clad in glass, tall buildings become a prime killer. Approximately 98% of flying vertebrates (birds and bats) migrate at heights below 500 m (1640 ft), and today, tallest buildings in the world reach or come close to the upper limits of bird migration paths. Although bird migration happens in fall and spring seasons, their collision into tall buildings occurs year-round [88].

At night, skyscrapers' lights lure birds in search of navigational cues. Birds usually use stars and the moon, and illuminated windows often divert them from their original flight paths. As such, birds can be attracted to artificially lit tall buildings resulting in collisions. This problem manifests on evenings of inclement weather, when the cloud's altitude is low, which forces birds to fly at lower heights. Attracted by the artificial light rays, some birds collide into the buildings' facades. Ironically, "building green" promotes incorporating bird habitats in cities (e.g., parks, gardens, roofs, and water surfaces) and demands incorporating plenty of glass to ensure the provision of daylight in buildings—a deadly combination for birds [89].

4.7. Waste Management

Tall buildings generate large volumes of waste because they house large population. On average, the disposal rate of an apartment unit is about one ton per year. While this amount of waste is not different from a low-rise residential unit, the method of waste collection in high-rises is more complicated than that in low-rises. One popular disposal method for tall buildings is the chute system, which consists of vertical shafts that transfer waste to a central location bin in a lower level of the building via gravity. Nevertheless, the large amount of waste accumulated on the ground floor poses a challenge to management systems. That is, massive waste can pile up quickly, and if the building management does not take care of the disposal rooms, a large amount of daily disposed waste can lead to overflowing collection bins that can cause odor and rodent problems. As such, collecting waste

by haulers must occur more than once a week, which is the norm with single-family residential trash pick-ups [59].

In other cases, residents of tall buildings haul their household trash by themselves to a central location usually in the basement of the building where waste management collects in roll-off or standard refuse containers. Overall, this method is the most labor intensive for residents, and most high-rise cities continue to apply this method. Further, because tall buildings have different layouts, forms, and shapes, disposal and collection systems vary from one building to another [59].

While increasingly cities enact recycling goals, high-rise apartments have remained largely immune to recycling. The complex methods of collecting waste coupled with confined spaces in high-rises make it harder to implement recycling systems. Also, loading docks have limited space for containers, and service-parking areas are small, thereby making it harder for trucks to maneuver, load waste, and leave the site. Further, research illustrates that apartment residents are less committed to recycling than other types of housings because they lack a sense of ownership. Additionally, buildings' owners do not hire companies to conduct recycling to avoid raising rent [59].

Overall, because of rapid urbanization, the issue of waste management is increasingly significant. Cities often lack waste-recycling facilities, regulations on the disposal of construction waste, and management of dumping sites. Furthermore, numerous cities face problems of illegal dumping and are short of landfill sites [90].

5. Conclusions

Tall buildings are becoming increasingly an integral response to massive urbanization. However, this building typology has unique challenges and issues, and therefore, planners, architects, community leaders, politicians, and the public at large bear the responsibility of finding effective ways to integrate them in cities in a sustainable manner. In this regard, Wim Bakens explains, "Tall buildings represent the most challenging building typology from many points of view, and they will influence, for better or worse, the future of cities worldwide. It is in our possibilities to turn tall buildings into nice, affordable and sustainable places to live in, and academic and industry research is the way forward" [91]. Sustainability is a topic that applies to all levels of tall buildings development, design, and planning, from the choices of structural systems and finishing materials to the relationships of indoor and outdoor spaces to integration with the larger urban context.

This paper has reviewed and examined a wide-range of concerns about tall building developments, and organized critiques by using the concept of sustainability as a framework. The purpose is to raise awareness about problems with this building typology. In some incidences, social failure and isolation in high-rise development, due to lack of healthy neighborhood relations and poor design, have led to depression and discomfort. There have been examples in which tall buildings were aimed for the top of the social scale for economic reasons, and as a result, these newly introduced buildings were socially segregated from the rest of the neighborhood. Rather than blending into the neighborhood, they created social enclaves or "vertical gated communities". Skyscrapers could not be "sustainable" if they were placed away from public transit, amenities, schools, stores, hospitals, and other important services. A disintegrating spatial arrangement may provide a new form of "vertical sprawl" that promotes an inefficient use of land and results in the generation of more greenhouse gas emissions.

Economically, tall building construction requires an extra premium because of their need for sophisticated foundations, structural systems, and high-tech mechanical, electrical, elevator, and fire-resistant systems. Also, a large core area is needed to accommodate elevators and building services systems. While 70% of a skyscraper's space is usable (the remainder being the building's elevator core, stairwells, and columns), more than 80% of low-rise spaces are typically useable. Tall buildings also suffer from higher operation costs, such as elevator maintenance and emergency response preparedness. Also, in difficult economic times, towers simply may not generate enough sales or rental value to support the high quality of design, materials, and detailing. This situation risks producing low-quality towers that maximize floor area at the expense of sound design.

An important design consideration is the impact of tall buildings on the urban microclimate and the shadows that they might cast during daytime over the pedestrian realm, including parks, plazas, and streets [18]. Urban design studies require a greater analysis of shadow patterns, such as seasonal and regional effects. In cities that experience an extended period of cool autumn and spring seasons, and a cold winter season, the availability of direct sunlight to areas of pedestrian activity plays an important role in supporting the use of pedestrian areas. Frequently, during these seasons, the availability of the sun's warmth makes walking on a street, or sitting in a park or plaza tolerable and often inviting, whereas these areas in the shade may be quite uncomfortable.

This paper, however, does not conclude that all tall building developments are unsustainable. That is, not all the reviewed critiques apply to every tall building. These critiques vary largely based on place, culture, climate, location, and quality of design and construction. For example, in a mild climate, tall buildings that embrace natural lighting and ventilation do not necessarily consume more energy than other building typologies. In some countries, such as Singapore, excellent design coupled with cultural practices has resulted in socially successful high-rise developments [92–94].

In fact, a new crop of “sustainable” skyscrapers is on the rise. That is, an increasing number of architects believe that the prevailing sustainability trend is directing us to generate a new generation of skyscrapers, named the “fifth generation”, that aims for energy saving and a carbon-neutral footprint. In his recent article (2016) titled “Why Efficient Skyscrapers Will be Essential to Cope with Growing Urban Populations” David Nicholson-Cole demonstrates this trend by explaining, “These exceptional new towers include a variety of eco-friendly innovations, such as renewable energy generation, solar shading and double-skin facades with natural ventilation. They will also feature greater thermal mass, landscaped atriums, underground heat storage, water catchment, recycling, linear induction elevators, as well as vertical urban farms, green planting, and facades and roofs that generate electricity” [95]. For example, the recently completed Tower at PNC Plaza, Pittsburgh sets a new benchmark in sustainability by employing features such as natural ventilation, optimal solar orientation, water recycling, and waste diversion, among others. Earlier, the Hearst Tower in NYC employed a diagrid structure that saved 2000 tons of steel and used 26% less energy than a building constructed to normal code. Ninety percent of utilized steel was made from recycled material. Further, developers imported merely 10% of all its materials, reducing cost and carbon emissions [95].

Overall, the path to creating a sustainable vertical city is not easily attainable; there are certain challenges that need to be addressed, as this paper attempted to outline. Architects and planners will face obstacles, difficulties, and challenges that are likely not found in low-rise developments. Hopefully, when tall buildings are well designed and integrated into their cities, they will be able to efficiently house a large number of inhabitants, while increasing city’s vibrancy, synergy, and economic activities. Simple, elegant, and logical design, coupled with the exploration and experimentation of new forms, likely will offer suitable, contemporary habitats. Ultimately, by embracing modern technology, local culture, local context, the natural environment, and cost effective solutions, we can collectively set humanity on the path of creating sustainable cities.

6. Future Research

Researchers need to conduct significant work at the planning, architectural, and engineering levels in the design, construction, and integration of the skyscraper into cities. While this paper attempted to identify the “unsustainable” aspects of tall building developments, a follow-up paper could attempt to provide the remedies and solutions to these problems. Further, at the design and planning level, this paper has provided an umbrella approach that did not differentiate among the different types of tall buildings. As such, future research may focus exclusively on residential, or office, or mixed-use tall buildings. It may also differentiate between government-sponsored versus private developments.

Management of the building, evaluation of its performance and assessment of tenant satisfaction are also essential components to achieving more sustainable skyscrapers [96]. “Greenwashing” or “bogus sustainability” is becoming mainstream criticisms of sustainable tall buildings. We continue

to lack a solid grasp of the full implications—the physiological, psychological, social, economic and environmental implications—of vertical living, that entail cramming greater numbers of people into smaller spaces. This requires additional research that studies the implication of integrating these urban giants in cities [97,98].

In particular, future research should examine the social sustainability of tall buildings in depth. There is a need to investigate the impact of high-rise living on social behavior and community and lifestyle in different places and cultures. Given the world's aging population, we have to examine the needs of the elderly and disabled concerning high-rise living. In addition, it would be useful to do more research on inter-generational living. High-rise design should reflect the significant differences in needs of seniors versus young single professionals, or families with children. Finally, research on the big E (equity) in the triple bottom line is lacking [99,100].

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