Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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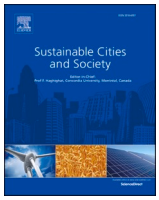

Towards building resilient cities to pandemics: A review of COVID-19 literature

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ABSTRACT

With the global prevalence of COVID-19 disease, the concept of urban resilience against pandemics has drawn the attention of a wide range of researchers, urban planners, and policymakers. This study aims to identify the major dimensions and principles of urban resilience to pandemics through a systematic review focused on lessons learned from the COVID-19 pandemic and comparing different perspectives regarding resilient urban environments to such diseases. Based on the findings, the study proposes a conceptual framework and a series of principles of urban resilience to pandemics, consisting of four spatial levels: housing, neighborhoods, city, and the regional and national scales, and three dimensions of pandemic resilience: pandemic-related health requirements, environmental psychological principles, and general resilience principles. The findings show that resilient cities should be able to implement the pandemic-related health requirements, the psychological principles of the environment to reduce the stresses caused by the pandemic, and the general principles of resilience in the smart city context. This framework provides scholars and policymakers with a comprehensive understanding of resilience on different scales and assists them in making better-informed decisions.

1. Introduction

On March 11, 2020, World Health Organization (WHO) declared COVID-19 a pandemic (World Health Organization, 2020). According to WHO, the COVID-19 pandemic has led to the infection of about 623,479,824 people and the death of 6,625,763 people worldwide (WHO, 2022). Aside from the high mortality rate, this pandemic has led to ongoing problems and widespread global disruptions that have impacted people's lives in many aspects (Shakil et al., 2020).

Like natural disasters, pandemics cause social, organizational, and economic disruptions. Therefore, it is no surprise that COVID-19 has caused significant disruptions at all levels in terms of social impacts, from national lockdowns to self-isolation, resulting in adverse effects on small businesses and the overall economy (Sakurai & Chughtai, 2020). Moreover, cities are particularly impacted by local and global connectedness, high levels of human mobility, and a high concentration of economic activities. Therefore, it is unsurprising that cities have been epicenters of the pandemic in different parts of the world (Kummitha, 2020). Consequently, there have been renewed debates over the role of urban planning and design in controlling diseases on the one hand and maintaining the viability and economy of cities on the other hand.

Until 2020, there was limited research on the role of urban planning and design in controlling pandemics. Most policymakers mainly focused on short-term solutions, such as the lockdown of cities, public transport closure, and social distancing to manage the pandemics' risks. The main reason behind this lack of contribution is little to no consideration of calamities like pandemics in such domains (Allam & Jones, 2020) since pandemics do not frequently occur, unlike other disasters and stressors. In addition, contrary to natural disasters, pandemics often directly threaten people and the economy, not the infrastructure and built environment. Therefore, the proposed solutions are more related to public economic policy and public health issues than the need to protect or rebuild infrastructure (Litman, 2020). Another reason is that pandemics are often unpredictable, and each pandemic probably needs different design strategies (WHO, 2018). Furthermore, urban planning and design are long, drawn-out processes taking years, while reactions

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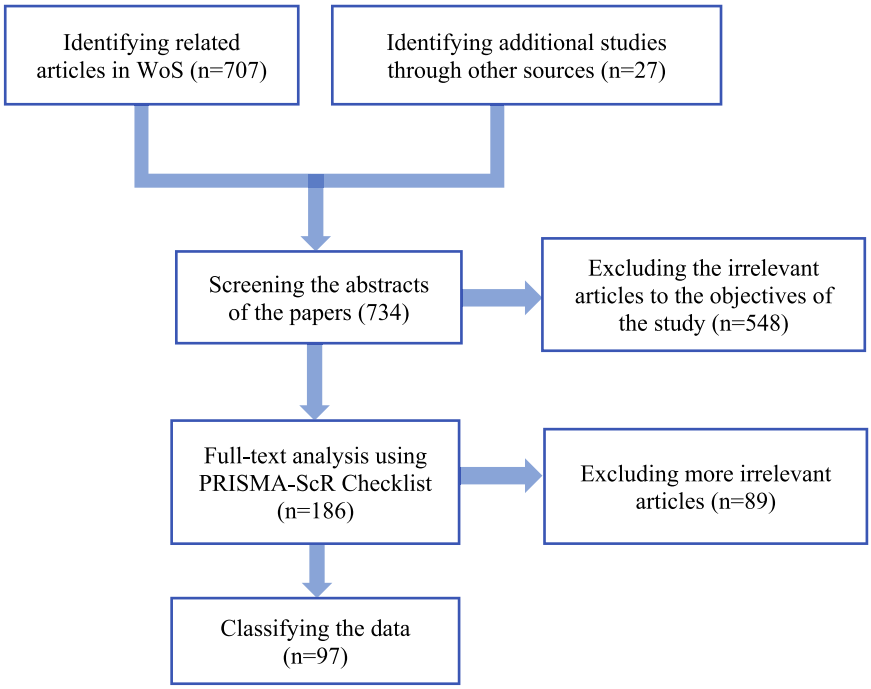


Fig. 1. Procedures for literature search and selection of articles through the research phases. Source: adapted from Moher et al. (2009).

to pandemics are often "just-in-time" reactions.

Although resilience has been widely used for several decades in various fields, such as physics, ecology, psychology, and economy, it is a relatively novel concept in urban planning and design (Sharifi & Yamagata, 2016). About two decades ago, the resilience concept gained ground within urban planning and design (Sharifi & Yamagata, 2018a). Since then, it has been increasingly used as an organizing framework to guide scientific and political discourses in many urban contexts (Sharifi & Yamagata, 2018b). However, the main focus of resilience in urban planning and design has been on the resilience of cities and their different subsystems against adverse events such as floods, earthquakes, tsunamis, and wildfires, not pandemics. But the COVID-19 pandemic showed how different characteristics of cities play critical roles before (prevention), during (reduction through segregation), and after (planning and risk management strategies for the future) pandemics (Block et al., 2020; Lai et al., 2020).

Therefore, this study seeks to identify the main dimensions that form the resilience of cities to pandemics, the spatial scales that urban planners and policymakers need to consider in planning for pandemic resiliency of cities, the measures that should be adopted to improve the resilience of cities to pandemics, the importance of health protocols in resilient cities to pandemics, and the role of environmental psychology in reducing peoples' stress level in cities. For this purpose, the literature on this topic is reviewed, and a conceptual framework presenting the identified dimensions, and spatial levels is introduced. The presented framework and the proposed principles can be effective in post-COVID urban planning and help practitioners and decision-makers to take action toward building more resilient cities in the face of pandemics.

2. Materials and methods

To address the research objectives, relevant studies were selected based on the systematic-review framework of Moher et al., (2009). To identify the main concepts, theories, and knowledge gaps, the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist was used (Tricco et al., 2018). Then, each section of the PRISMA-ScR Checklist was categorized using the inductive content analysis method. In the following paragraphs, each step is explained in more detail.

First, a broad search was conducted on the Web of Science (WoS) on March 25th, 2022. The search was limited to English-published studies, using the search string:

(TS=("pandemic*" OR "epidemic*" OR "corona*" OR "covid*") AND TS=("urban*" OR "city" OR "built environment") AND TS=("resilien*"))

This search returned 707 articles, and 27 more papers were also found by searching Google Scholar and screening the articles' references. Then, the abstracts of all the 734 studies were examined to find the most relevant ones to this study. In this step, the studies that included the characteristics of cities, which are more resilient against coronavirus, or resilient urban design against pandemics, were identified. Thus, 548 studies related to the COVID-19 pandemic but not focused on the scope of this study were excluded.

The next step was extracting and categorizing the data. In this step, the remaining 183 studies were explored using the PRISMA-ScR Checklist to find information related to urban resilience to pandemics and different resilience attribute(s) and categories. The information on all studies was covered and categorized into 22 items of the PRISMA-ScR Checklist. Then, the information in each article was further sub-classified into different categories via qualitative inductive content analysis. Therefore, the information in each item was further sub-classified into different categories via qualitative inductive content analysis. Thus, the information under each section of the present study was obtained inductively as the articles were examined. An Excel spreadsheet was developed to store the extracted data. As we continued the content analysis of the studies, new data were added to the existing categories. If not relevant to existing classes, new ones were created. This process continued until all articles were covered. Therefore, the categories were refined throughout the review process, and data with similar themes were classified into the same groups until all the data was covered. This method inductively extracted new ideas from the previous literature and reduced researchers' bias. Using the systematic review method allowed the researchers to cover the data as much as possible, compare different ideas, avoid redundancy, and classify the data with similar themes into the same categories.

As a result of a comprehensive systematic literature review and following data categorization based on inductive content analysis, the

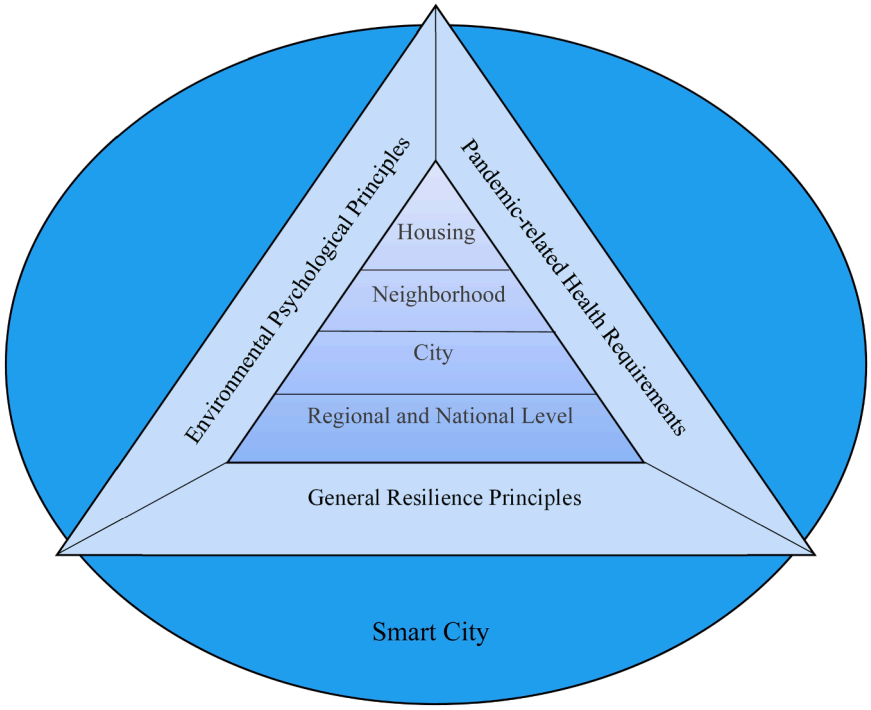


Fig. 2. A conceptual framework for resilient cities to pandemics.

issues related to urban resilience to pandemics were classified into four categories: 'the pandemic-related health requirements', 'the environmental psychological principles', 'the general principles of resilience', and 'the smart city'. In addition, four spatial scales were identified: 'housing', 'neighborhood', 'the city', and 'regional and national'.

Because other studies were published since we first started our search in 2022, we considered their insights in our study even though they were not part of the systematic search. Furthermore, the study's methodology enabled us to include many relevant studies in the reviewing process. Although other relevant studies might not have been included, the number of reviewed studies was sufficient to achieve the study's objectives. The reviewing process continued until data saturation, and adding more papers would probably not alter the results. Fig. 1 shows the process of selecting related studies and their analysis.

3. Results and discussions

3.1. Urban resilience and resilient cities to pandemics

In 1973, Holling (1973) introduced the term "resilience" in the ecological literature in his study, Resilience and Stability of Ecological Systems, for the first time. He defined resilience as a way to understand the dynamic and nonlinear stresses absorbed in the ecosystem and the amount of perturbation that can be absorbed by the ecosystem so that it can remain stable without significant changes in its structure. Although the initial definitions of the concept are often focused on the resistance of a system or returning to the equilibrium after experiencing a shock or a sudden change (Ludwig et al., 1997; Pimm, 1991), today, resilience is considered to be a broader concept that recognizes the importance of adaptation and non-equilibrium dynamics that is not focused solely on sudden shocks or disruptions (Amirzadeh & Barakpour, 2021; 2019a).

In recent years, many studies have used the concept of resilience in "urban systems". Some researchers have described cities as complex and adaptable social-ecological systems. They argue that resilience provides a valuable perspective for ecologists, planners, and other involved actors in urban development in the face of uncertainties (Orleans Reed et al., 2013). The idea of urban resilience generally indicates the ability to adapt and respond positively to shocks and changes in an urban system (Desouza & Flanery, 2013). Meerow et al. (2016: 42–45) noted that there are six conceptual differences related to resilience definitions in previous research: "(1) definition of 'urban'; (2) understanding of system equilibrium; (3) positive vs. neutral (or negative) conceptualizations of resilience; (4) mechanisms for system change; (5) adaptation versus general adaptability; and (6) timescale of action". The concept of urban resilience is related to studying how ecological systems adapt to disruptions caused by external factors (Davic & Welsh, 2004). This concept is generally about how an urban system can withstand a wide range of disturbances (Leichenko, 2011). These urban stresses are not situated in one area but, as Buckman & Rakhimova (2020) point out, are part of an interconnected structure that includes the environment, governance, economics, and community. Thus, it is essential to see urban resilience as a multi-dimensional concept in a way that neglecting some aspects of it leads to incomplete and incorrect conclusions about this concept (Amirzadeh & Barakpour, 2019b; Buckman & Sobhaninia, 2022; Jabareen, 2013).

Despite considerable attention to urban resilience and its frequent usage, this concept has remained ambiguous, with different interpretations in policy and academic discussions about cities (Amirzadeh et al., 2022; Sobhaninia & Buckman, 2022). Even though there are various interpretations of this concept, one of the best definitions was presented by Meerow et al. (2016). They (2016: 42–45) defined urban resilience as "the ability of an urban system – and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales – to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to transform systems quickly that it limits current or future adaptive capacity". However, after reviewing the literature, it can be concluded that in addition to these resilience features, resilient cities to pandemics should also have healthy and stress-free environments (Gu et al., 2020; Megahed & Ghoneim, 2020; Tokazhanov et al., 2020). Therefore, urban resilience to pandemics can be defined as the ability of an urban system to continue its desired function and provide a sanitary and stress-free environment for its citizens during different stages of pandemics.

After analyzing the literature on resilient cities to pandemics,

different categories for the data were obtained, which are shown graphically in Fig. 2. The framework in Fig. 2 includes three essential dimensions of resilient cities to pandemics: Pandemic-related Health Requirements, Environmental Psychological Principles, and General Resilience Principles in the context of a smart city. The more cities are transformed to include requirements for improving the resilience of cities to such diseases, the faster the control of the disease and the improvement of people's life quality during pandemics will be. Moreover, according to the comprehensive systematic review, resilient city features can be classified into four spatial levels: housing, neighborhood, city, and the regional and national scales. These four spatial levels are graphically shown in Fig. 2 based on their scale, with the housing having the smallest and regional and national levels having the biggest scale. It is important to note that the three dimensions of a resilient city to pandemics cover all four primary spatial levels identified through the systematic review. Furthermore, due to the constant emphasis on the importance of smart cities since the COVID-19 pandemic (Afrin et al., 2021; Harris et al., 2022; Jaiswal et al., 2020; Kunzmann, 2020; Sharifi et al., 2021), the role of smart cities cannot be ignored in times of pandemics and therefore, these dimensions are considered in the context of the smart city in the proposed framework, which will be discussed more in the following paragraphs.

A "smart city" is considered a high-tech intensive and advanced city that uses technology to link people, information, governance, economy, and city elements to create a sustainable, greener, and competitive cities with a higher quality of life (Bakıcı et al., 2013). Using smart city technologies has been considered influential in different aspects such as patient tracing (Afrin et al., 2021; Sonn et al., 2020), transportation (Gupta et al., 2020), social distancing, medical drones (Jaiswal et al., 2020), recognizing the outbreaks, determining the available resources, drone supply delivery, virtual communication, tracking patient numbers, predicting available hospitals (Inn, 2020), and monitoring facial mask practices (Rahman et al., 2020). However, smart city tools should be adapted based on pandemic disasters to ensure urban health. Allam and Jones (2020) highlighted the importance of standardization of protocols to improve smart city communication and democratization of technology to encourage equity and transparency and, eventually, more cooperation in times of disasters.

The triple dimensions, which were classified based on the literature review on pandemic-resilient cities and experiences from COVID-19, are explained in the following paragraphs.

3.1.1. Pandemic-related health requirements

In general, the design principles for health crises such as pandemics are different from other disasters since biological crises often threaten the health of communities (Litman, 2020). Pandemic-related health requirements refer to all measures that help prevent the transmission of viruses during pandemics. The experience of the COVID-19 outbreak showed that cities need to enable the implementation of health requirements related to infectious diseases to maintain the function of the urban environments. In other words, urban environments capable of implementing such measures would adapt to such a crisis quicker and better, therefore, showing a higher level of pandemic resiliency.

Although social distancing and lockdown were the key measures introduced by WHO (Salama, 2020), Megahed and Ghoneim (2020) emphasized reducing the population density since overcrowding in public areas in times of pandemics leads to unsanitary conditions and more spreading of infectious diseases. Moreover, the role of ventilation and airflow in airborne transmission of infectious disease, particularly in indoor spaces, was another health measure that was highlighted in the literature (Gao et al., 2009; Gu et al., 2020; Li et al., 2007). Smart technologies and indoor finishing materials (Megahed & Ghoneim, 2020; Tokazhanov et al., 2020; Van Doremalen et al., 2020) are other health measures mentioned in the literature.

Table 1
Summary of requirements of resilient cities to pandemics.

Category	Subcategory	Ref.
Pandemic-related health requirements	Social distancing Lockdown and quarantine Reducing the population density Indoor ventilation, air quality, temperature, and humidity Smart technologies Indoor finishing materials	Atalan (2020); Guo et al. (2021); Melone & Borgo (2020); Baser (2021); Bhadra et al. (2021); Block et al. (2020); Kadi and Khelfaoui (2020); Lee et al. (2021); Sy et al. (2021); Gao et al. (2009); Gu et al. (2020); Li et al. (2007); Megahed & Ghoneim (2020); Tokazhanov et al. (2020); Van Doremalen et al. (2020); Wong & Li (2020)
Environmental psychological principles	Maintaining social connections and facilitating social interaction Access to green and natural environment	Hartig et al. (2003); Johnson et al. (2021); Nitschke et al. (2021); Poortinga et al. (2021); Tokazhanov et al. (2020); Velarde et al. (2007)
General resilience principles	Decentralization Self-sufficiency Adaptability Flexibility Diversity Multi-functionality Modularity Connectivity Redundancy	Ahern (2011); Allan and Bryant (2012); Dhar and Khirfan (2016); Godschalk (2003); Sharifi and Yamagata (2015); Tanner et al. (2009); The Rockefeller Foundation, 2014; Toseroni et al. (2016); Tyler and Moench (2012)

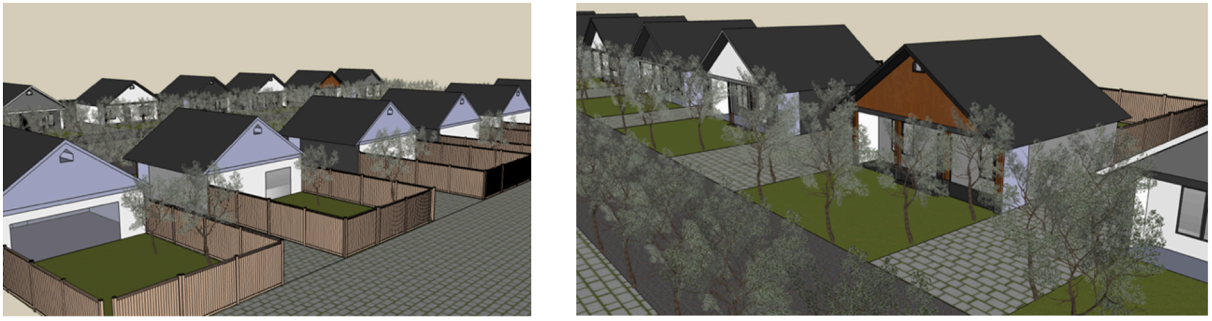
3.1.2. Environmental psychological principles

One of the most critical consequences of pandemics is social anxiety. The level of anxiety, fear, and despair among people indicates the vulnerability of communities facing danger (Zabaniotou, 2020). Thus, the role of health psychology in responding to a pandemic and life changes should be understood to minimize the stress caused by a disease outbreak (Arden & Chilcot, 2020; Bish and Michie, 2010). Some of the psychological regulations mentioned in previous studies are proper governance and social support (Dhar et al., 2020), accessible recreational activities, online psychological support, expansion of online educational opportunities (Akat & Karatas, 2020), maintaining social relationships and connectedness even online (Thakur & Jain, 2020), and timely and adequate health information (Tee et al., 2020). However, considering the role of urban planning and design in improving the resilience of cities to pandemics, the present study focuses on the crucial role of environmental psychology in reducing people's stress level in cities. This dimension includes factors such as facilitating social interactions while maintaining social distancing (Johnson et al., 2021; Nitschke et al., 2021; Poortinga et al., 2021) and access to green and natural environment (Tokazhanov et al., 2020; Hartig et al., 2003; Velarde et al., 2007).

3.1.3. General resilience principles

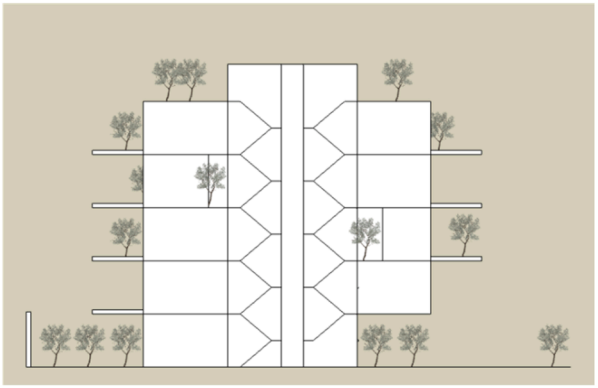
A literature review on resilience shows that many researchers and institutions have provided resilience indicators. The general characteristics of resilience presented by researchers over time such as self-sufficiency, self-organization, decentralization, diversity, multi-functionality, flexibility, adaptability, modularity, connectivity, and inclusiveness (Ahern, 2011; Allan & Bryant, 2012; Dhar and Khirfan, 2016; Godschalk, 2003; Sharifi & Yamagata, 2015; Tanner et al., 2009; The Rockefeller Foundation, 2014; Toseroni et al., 2016; Tyler & Moench, 2012) are also applicable to the urban pandemic resilience.

The summary of resilient cities' requirements for pandemics is



- Private natural environment for each housing
- Private front porch and back yards for each house
- Facilitating the private accessibility to natural lighting and fresh air
- Opportunity to plant vegetables for households

Single-family detached housing examples.



- Private natural environment for each household through their balconies
- Private front porch and back yards for the building
- Facilitating the private accessibility to natural lighting and fresh air
- Different vertical access
- Private green roof for the building

Multi-family housing example, which involves the positive features of single-family detached housing.

Fig. 3. Comparison between the two types of housing: single-family detached housing and multi-family housing, which involves the positive features of single-family detached housing.

provided in Table 1.

3.2. Principles of urban resilience to pandemics

This section provides the principles of resilient cities to pandemics in four spatial levels: housing, neighborhood, city, and regional and national levels. Each level's principles also provide three subcategories (1) pandemic-related health requirements, (2) environmental psychological principles, and (3) general resilience principles. However, there were some overlaps between some principles, and some were common among two or three dimensions.

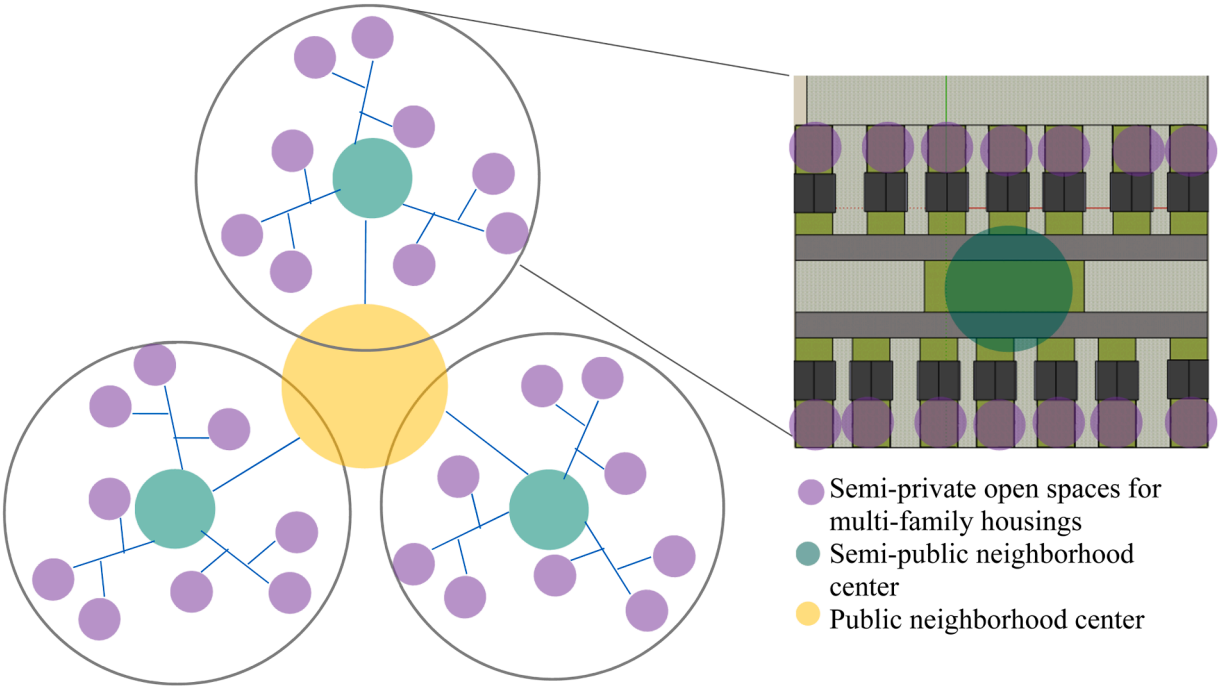
3.2.1. Housing

Historically, residential housing has been primarily designed to reflect the culture of its residents through construction, including the evolution of construction methods and approaches resulting from past disasters (Keenan, 2020). Therefore, reviewing the patterns and the housing codes is necessary to improve housing conditions to positively impact people's mental and physical health and their life quality during pandemics. According to the literature, the COVID-19 pandemic had valuable lessons for improving housing conditions during pandemics. The most important lessons are:

Pandemic-related health requirements: First, the COVID-19 pandemic emphasized the superiority of single-family housing with private open spaces, which provides the best environment and facilities for protective health measures, such as social distancing and the better use of light, fresh air, and nature (Megahed & Ghoneim, 2020). Although following this housing model may help solve the pandemic issues, it might result in urban sprawl. According to the resilience literature, urban planners and designers should keep advocating compact urban forms rather than sprawling ones due to the various merits of this form of urban development for urban resilience (Sharifi, 2019a; Sharifi, 2019b). Therefore, this study emphasizes that the best housing model for resilient cities to pandemics is multi-family housing, which involves the positive features of single-family housing, such as a private natural environment for each household and access to natural light and fresh air.

A comparison between the two types of housing is presented in Fig. 3.

Second, such houses should benefit from new technologies and materials to provide specific protective health measures for their occupants, such as applying artificial intelligence and touchless technologies (Tokazhanov et al., 2020). In multi-story and high-rise buildings, where contact with other residents in shared spaces is unavoidable, intelligent technologies, such as touchless door entry systems, automatic doors, voice-activated elevators, and hands-free light switches, should be used in buildings to provide touchless equipment from the main entrance door to the apartment door. Such structures should also have more



- Hierarchy of connected open spaces in different scales: public neighborhood center, semi-public neighborhood center, semi-private open spaces in multi-family housings
- Mixed-use neighborhood with multi-family housings
- Providing the weekly needs of residents in the neighborhood
- Private or semi-private natural environment for each household
- Facilitating the private accessibility to natural lighting and fresh air
- Opportunity to plant vegetables

Fig. 4. Resilient neighborhood example.

elevators and stairs with proper ventilation (Megahed & Ghoneim, 2020).

Third, antibacterial fabrics and materials on the surfaces. Antibacterial fabrics and finishes should cover buildings on surfaces to prevent the spread of viruses (Tokazhanov et al., 2020).

Fourth, regarding the design and layout of interior spaces, it is necessary to have more partitions between the areas so that in case of illness of any family member, it would be possible to quarantine the infected person. It is also recommended that residential housings have several separate bathrooms in case one family member gets infected (Tokazhanov et al., 2020).

Fifth, the proper ventilation and lighting of the interior of the housings are other essential factors in ensuring the health of residents (Li et al., 2007). This could be provided through both natural and artificial resources. However, natural airflow and lighting are more recommended.

Environmental psychological principles: First, due to the high stress level during pandemics and increased periods spent at home, one of the most critical principles is the inclusion of nature and airy spaces in residential environments. Natural elements such as plants, vegetation, and private green spaces help lower blood pressure and stress hormone levels and boost immunity (Hartig et al., 2003; Velarde et al., 2007).

Second, open or semi-open spaces such as courtyards, balconies, terraces, and accessible roofs can provide residents with areas to enjoy the fresh air and sunlight and engage in physical activities such as sports and games while maintaining social distancing. Such places act as buffer zones between the house and the unsafe outside (Melone & Borgo, 2020). They are an alternative to inaccessible public areas such as streets, urban squares, and parks in times of pandemics (Poortinga et al., 2021). They also satisfy the need for the "third place" to some extent (Banai, 2020). Therefore, these spaces prevent vulnerable groups' isolation and help improve social interactions among individuals.

General resilience principles: First, "adaptability" is one of the most critical features highly emphasized in the literature on resilience. In the literature post-COVID-19, the intimacy of social relationships for members of the family, who work remotely in spaces designed primarily for entertainment and domestic pursuits, was highlighted (Keenan, 2020). Lack of personal privacy and adequate housing space for work, study, and exercise can lead to a higher stress level for residents. Therefore, with the emerging need to work from home, designers should pay more attention to creating comfortable, isolated, and adaptive layouts in housing and multipurpose furniture (Tokazhanov et al., 2020).

Second, "self-sufficiency" is another feature highlighted in the literature on resilience (Ahern, 2011; Allan & Bryant, 2012; Dhar and Khirfan, 2016; Godschalk, 2003; Sharifi & Yamagata, 2015; Tanner et al., 2009; Tyler & Moench, 2012). As well as naturally filtering the air, green spaces would also provide residents with the opportunity to produce vegetables and fruits, leading to the relative self-sufficiency of households.

3.2.2. *Neighborhoods*

The importance of neighborhood design is heightened during the COVID-19 pandemic since residents are more willing and sometimes forced to spend more time at their houses and in their immediate neighborhoods (Miao et al., 2021). Studies show that neighborhoods with different socioeconomic features impact their residents differently

during COVID-19, and not all people are at equal risk (Biggs et al., 2021; Hatef et al., 2020). Neighborhood socioeconomic characteristics, such as race, ethnicity, and income level, are associated with social vulnerability during the pandemic (Feldman & Bassett, 2020; Hatef et al., 2020).

Apart from socioeconomic features, several physio-spatial characteristics impact community resilience. The following paragraphs summarize the literature on neighborhood features that contribute to improved resiliency.

Pandemic-related health requirements: First, access to basic essential services, including living, working, commerce, healthcare, education, and entertainment facilities within a 15 min walking or cycling (Moreno et al., 2021). The concept of "15 min City", which has been discussed frequently in the literature, emphasizes planning based on proximity to such services in a neighborhood (Allam et al., 2022; Balletto et al., 2021; Guzman et al., 2021; Pozoukidou & Chatziyiannaki, 2021).

According to the proponents of this concept, residents would experience a higher quality of life within a 15-min radius. Moreno et al. (2021) believe this model has different environmental, social, economic, and health benefits. The 15-min city implies a shift in the emphasis of planning from the neighborhoods' access to urban facilities to the proximity of urban facilities within neighborhoods (Pozoukidou & Chatziyiannaki, 2021). In the case of pandemics, the proximity of essential services would also decrease the need for communication within the cities, which was considered one of the major contributing factors to COVID-19 transmission during the pandemic (AbouKorin et al., 2021; Megahed & Ghoneim, 2020).

Second, urban green infrastructure and natural environments at different scales in neighborhoods improve air quality, provide safe spaces for different groups of residents, improve people's quality of life, and increase the possibility of social interactions among residents in times of pandemics (Jenkins, 2020).

Environmental psychological principles: Urban designers should provide a hierarchy of places, from public and semi-public to semi-private open spaces, in the design of neighborhoods to facilitate outdoor activities, allowing residents to exercise, play, and plant vegetation during pandemics. Such areas contribute to the physical health of residents by decreasing the adverse consequences of quarantine and the closure of cities on the individuals' mental health, as well as preventing the congestion of public spaces on the scales beyond neighborhoods in the city (Lak et al., 2020).

General resilience principles: First, the COVID-19 pandemic showed that the best model for developing neighborhood structures is creating relatively independent neighborhood units/modules to provide the weekly basic needs. This idea is consistent with "self-sufficiency" and "modularity" criteria in the literature on resilience (Ahern, 2011; Allan & Bryant, 2012; Dhar and Khirfan, 2016; Godschalk, 2003; Sharifi & Yamagata, 2015; Tanner et al., 2009; Tyler & Moench, 2012). The opportunities for agricultural activities in the neighborhood can also lead to self-sufficiency in providing food for residents during these periods.

Second, the concept of traditional mixed-use neighborhoods is one of the basic requirements of resilient cities during pandemics. Providing communities with ample public facilities minimizes the need for traveling within the cities. This idea is consistent with diversity, one of the basic general principles of resilience (Ahern, 2011; Allan & Bryant, 2012; Dhar and Khirfan, 2016; Godschalk, 2003; Sharifi & Yamagata, 2015; Tyler & Moench, 2012). In addition, due to travel restrictions in cities in the first stages of the pandemic, essential services in these neighborhoods must be within walking and cycling distance from residential houses.

Fig. 4 shows the resilient neighborhood example.

3.2.3. City

Many researchers have analyzed the resilience of urban and environmental elements to pandemics such as COVID-19. These elements include the role of green spaces (Pan et al., 2021; Samuelsson et al., 2020), population density (Lee et al., 2021; Wong & Li, 2020), neighborhood and social vulnerability (Miao et al., 2021), trust in political leadership (Fernández-Prados et al., 2021), infrastructure and their adaptive functionality (Hynes et al., 2020), and information system (Sakurai & Chughtai, 2020). Thus, according to the literature, the COVID-19 pandemic has had valuable lessons for cities' physical form and spatial structure. The most important lessons are:

Pandemic-related health requirements: First, the form of cities matters. In a study on European cities, AbouKorin et al. (2021) argued that city form was associated with the COVID-19 spread. Their study categorized cities' urban forms as linear, grid, and radial. They concluded that linear morphologies are linked to the lowest rates of infection. In contrast, cities with grid and radial forms had significantly higher infection rates during the COVID-19 pandemic.

Second, access to a green and natural environment is essential (Tokazhanov et al., 2020; Hartig et al., 2003; Velarde et al., 2007). Even though some researchers believe that a higher risk of infection accompanies more access to public green spaces as the possibility of interacting with people increases (Pan et al., 2021), many researchers found a positive relationship between green spaces and reduced risk of COVID-19 (Engemann et al., 2019; Hubbard et al., 2021; Orioli et al., 2019; Russette et al., 2021; Venter et al., 2021). Urban green space affects people's physical and mental health as well as the ecosystem (Ugolini et al., 2020). Green spaces are believed to have different impacts on health improvements (Engemann et al., 2019; Hubbard et al., 2021; Orioli et al., 2019) and are crucial health resources in times of crisis (Poortinga et al., 2021) by increasing happiness and life satisfaction, and decreased depression and loneliness in times of lockdowns (Soga et al., 2021). Killgore et al. (2020) emphasized the importance of green spaces and noted that the average resilience to COVID-19 is greater among people who can access green spaces more often. Majewska et al. (2022) declared that access to green spaces was essential to residents' quality of life in Polish towns and cities during the pandemic.

Poortinga et al. (2021) highlighted the importance of perceived public and private green space in people's health and well-being. Venter et al. (2021) reinforce the value of urban nature during and after a crisis and found a positive relationship between the lockdown in Oslo and the increasing usage of urban green infrastructure. In Italy, Ugolini et al. (2021) found an increased visit to nearby gardens and green spaces due to social distancing and other movement restrictions. Thus, crises such as COVID-19 highlight the values associated with public areas such as parks and natural environments (Keenan, 2020) since they can be accessible to those without a private garden (Poortinga et al., 2021). Therefore, plans for including green spaces and public spaces for leisure and recreation should be prioritized. Moreover, parks and green spaces should be located close to people, and accessibility should be considered for all users through various approaches, including bicycle and pedestrian connections (Slater et al., 2020).

Third, open and public spaces should be wide enough to provide social distance (Melone & Borgo, 2020). In addition, the appropriate width of the street and the general traffic flow also provide better access to medical centers and disease control, especially in times of illness (AbouKorin et al., 2021).

Environmental psychological principles: The diversity of open and semi-open urban spaces. Maintaining social connections is essential for our well-being during an unprecedented lockdown to prevent stress and fatigue (Nitschke et al., 2021). The variety and abundance of urban areas combined with parks and green spaces and their connection with pedestrian and bicycle paths in cities play an essential role in creating safe spaces for residents and the possibility of social interaction in pandemic situations (Johnson et al., 2021). Inclusive urban areas facilitate the presence of different groups, especially the elderly and sensitive groups, and prevent the isolation of people and possible mental illnesses, such as depression and anxiety.

General resilience principles: First, the "decentralization" of

facilities and population (Pisano, 2020), as well as facilitating walkability and biking in cities, should be prioritized (Majewska et al., 2022; Moreno et al., 2021). Since the physical closeness between infected and non-infected people carries the highest risk, urban services, especially medical centers and hospitals, must be distributed at different scales in the city. In addition, in a pandemic, when there is a fear of public transport congestion due to the risk of getting the disease, walkability is considered one of the essential principles to preventing disruption of activities and daily life in cities (Banai, 2020). Furthermore, bicycling infrastructures and programs, especially the Bicycle Sharing System (BSS), play a vital role in meeting the transportation needs of citizens and are a viable alternative to public transportation, as they are compatible with social distancing (Chen et al., 2022; Teixeira & Lopes, 2020). Moreover, sustainable transportation options such as bicycles and facilitating walking in the city minimize air pollution, which can improve the condition of infected individuals.

Even though the decentralization of facilities and population is suggested in cities, there are contradictory views on the effects of density on the COVID-19 spread (Barak et al., 2021; Carozzi et al., 2020; Hong & Choi, 2021; Khavarian-Garmsir et al., 2021). On the one hand, some believe that population density is an effective predictor of infection (Atalan, 2020; Lee et al., 2021; Wong & Li, 2020), and COVID-19 transmission was faster in areas with higher density because of an increase in contact rate between people (Baser, 2021; Bhadra et al., 2021; Block et al., 2020; Kadi and Khelfaoui, 2020; Sy et al., 2021). On the other hand, some believe density is not significantly associated with the infection rate resulting from more social distancing guidelines and a better healthcare system (AbouKorin et al., 2021; Hamidi et al., 2020;; Gaisie et al., 2022). Majewska et al. (2022) argued that cities should have a compact structure with a high population density to reduce commuting during pandemics.

Second, the "self-sufficiency" of cities and towns is essential. Majewska et al. (2022) suggest that towns should follow a polycentric settlement network form, which as well as allocating places for living, provides jobs, access to essential frontline services within walking distance, and agriculture. Moreover, strengthening self-sufficient communities through urban farming would improve the resilience of cities to pandemics by improving food security, lowering stress, and improving the air quality in cities. Therefore, horizontal and vertical urban gardens should be flourished in urban areas (Megahed & Ghoneim, 2020).

Third, "adaptable", "multi-functional", or "flexible" spaces are the most critical features of resilient urban systems (Ahern, 2011; Allan & Bryant, 2012; Dhar and Khirfan, 2016; Godschalk, 2003; Sharifi & Yamagata, 2015; Tanner et al., 2009; The Rockefeller Foundation, 2014; Tyler & Moench, 2012). Flexible urban spaces, which provide different uses simultaneously, allow the city to face uncertainties and changes ahead and accept future usages that are not considered in the current situation (Dhar and Khirfan, 2016). Modifiable and adaptable spaces in the city provide the necessary uses, such as establishing temporary hospitals during pandemics.

Fourth, the "redundancy" of public facilities needs to be considered (Pisano, 2020). Redundancy means "having more options than necessary from an efficiency perspective" (Giezen et al., 2015: 169). It is one of the essential characteristics of resilient urban systems (Ahern, 2011; Godschalk, 2003; Sharifi & Yamagata, 2015; The Rockefeller Foundation, 2014). The provision of redundant services at different scales in cities not only facilitates the accessibility of services for all groups of people but also minimizes the need for traveling within the cities and the consequent congestion in certain areas, which is a critical factor in the transmission of the disease in the time of pandemics.

Fifth, some scholars also pointed out the need for a connected system of green spaces in cities to improve resilience in the face of pandemics (Eltarabily & Elghezanwy, 2020). "Connectivity" is also one of the general resilience principles in the literature (Ahern, 2011; Dhar and Khirfan, 2016).

3.2.4. Regional and national level

Due to the nature and interconnectivity of issues at the regional and national levels, it was impossible to categorize the principles of this level into the triple dimensions (pandemic-related health requirements, environmental-psychological principles, and general resilience principles). Thus, they are discussed without the triple categorization in the following paragraphs.

First, the critical role of the urban-rural interface and urban-rural linkages must be acknowledged. Mitra et al. (2021) emphasized the crucial role of urban-rural connection for the collective security of food, energy, and water during the COVID-19 pandemic. Some scholars also highlighted the importance of preventative measures focused on the urban-rural interface to reduce exposure and control the transmission of the viruses (Polo et al., 2022; Wells et al., 2020). Due to the unprecedented movement restrictions, which disrupt people's lives during a pandemic, Sukhwani and Shaw (2022) considered pandemics a crisis for human security. Thus, they believe the urban-rural linkage should be revisited from a human security perspective to protect the survival and livelihood of people living in urban and rural areas.

Second, the extent of local autonomy in decision-making and disaster management could be a key factor. Sharma et al. (2021) discuss that a centralized governance structure would not lead to a proactive response to a pandemic. Some studies argue that city and city region levels were at the front line of coordinated action and leadership on COVID-19 during the pandemic (Sharifi & Khavarian-Garmsir, 2020). Harris et al. (2022) asserted that governance at these levels is essential for engagement with the public about preparedness for and resilience to pandemics. In a study on modes of policy coordination and policy responses to COVID-19 in China and the USA, Liu et al. (2021) concluded that national leadership should be balanced with local autonomy and public engagement to achieve effective governance in crises like pandemics.

Third, the "decentralization" of infrastructure across the country is essential. The role of infrastructure, including healthcare, water, energy, transportation, and communication, in the resilience of cities to pandemics has been highlighted in the post-pandemic literature (Sharma et al., 2021; Syal, 2021). Inadequate infrastructure in different parts of the country can lead to a higher level of vulnerability in different cities and hence, the spread of the disease (Syal, 2021)

Fourth, since cities are increasingly interconnected due to globalization, one of the most important issues regarding this scale is the "connectivity" among different cities (Kummitha, 2020). This connectivity could have a detrimental effect on preventing the spread of the disease during pandemics. Hamidi et al. (2020) concluded that connectivity among different cities negatively impacts the early spread of an epidemic disease. Metropolitan areas with more economic, social, and commuting relationships are more vulnerable to infections than less connected cities.

4. Conclusion

The present study highlights the role of architects and urban planners in improving urban resilience against future pandemics. This research aimed to identify the primary dimensions that form urban resilience, the spatial scales in planning that urban planners and policymakers need to consider, and the measures required to be adopted to achieve pandemic-resilient cities. A qualitative archival method was applied to achieve these objectives, and a wide range of literature related to resilience, particularly pandemic resiliency of cities, was reviewed through a systematic review.

The literature review showed that first, the significant dimensions of resilient cities to pandemics include (1) pandemic-related health requirements, (2) environmental-psychological principles, and (3) general resilience principles. Moreover, the triple dimensions should be considered in the context of the smart city concept. Second, the spatial scales that urban planners and designers need to consider in planning for

Table 2
Summary of principles of resilient cities to pandemics.

Spatial levels	Pandemic-related health requirements (H)	Environmental psychological principles (P)	General resilience principles (R)
Housing (H)	HH_1: Multi-family housing, which involves a private natural environment for each household and private accessibility to natural lighting and fresh air HH_2: Adding artificial intelligence and touchless technological equipment HH_3: Using antibacterial fabrics and materials on the surfaces HH_4: More partitions in the layout design -Including several separate bathrooms HH_5: Proper ventilation and lighting HH_6: Different vertical access with proper ventilation facilities in multi-family housing	HP_1: More green spaces to increase interaction with nature HP_2: Including open or semi-open spaces in the design	HR_1: Adaptive interior layout (Adaptability) HR_2: Private green spaces to produce vegetables and fruits (Self-sufficiency)
Neighborhood (N)	NH_1: Access to basic essential services, including living, working, commerce, healthcare, education, and entertainment facilities within a 15 min walking or cycling NH_2: Urban green infrastructure and natural environments at different scales	NP_1: A hierarchy of territories, ranging from public and semi-public to semi-private open spaces, to facilitate outdoor activities	NR_1: Relatively independent neighborhood units/ modules and providing opportunities to plant vegetables (Self-sufficiency and Modularity) NR_2: Mixed-use neighborhoods with diversity of public facilities and essential services (Diversity)
City (C)	CH_1: Linear morphologies CH_2: More public and private green spaces within the city limit CH_3: The appropriate width of public spaces to provide social distance and proper width of streets to facilitate better access to medical centers	CP_1: Diversity of open or semi-open public spaces to prevent stress and isolation of people	CR_1: Decentralization of population and facilities, as well as facilitating walkability and biking in cities (Decentralization) CR_2: Improving self-sufficiency through providing jobs, access to essential frontline services within walking distance, and urban agriculture (Self-sufficiency) CR_3: Modifiable and adaptable spaces in the city (Adaptability, Multi-functionality, and Flexibility) CR_4: Redundancy of public facilities (Redundancy) CR_5: A connected system of green spaces in cities (Connectivity)
Regional and national (R&N)	$R\&N_1$: Urban-rural connection for the collective security of food, energy, and water during the pandemics, as well as preventative measures focused on the urban-rural interface to reduce the exposure and control the transmission of the viruses $R\&N_2$: Local autonomy in decision making and disaster management $R\&N_3$: Decentralization of infrastructure, including healthcare, water, energy, transportation, and communication across the country $R\&N_4$: Less economic, social, and commuting relationships among different cities		

the resilience of cities to pandemics include housing, neighborhood, city, and regional and national levels. Finally, recommendations for building resilient cities to pandemics at all four levels and three dimensions were presented.

The summary of principles of resilient cities to pandemics is presented in Table 2.

While the present study identified improving the resilience of cities to pandemics should include a hierarchy of principles in four scales, including housing, neighborhood, city, and regional and national scales, some scholars stressed just one or two of the mentioned scales, such as city and architecture scales (Megahed & Ghoneim, 2020) or only housing scale (Tokazhanov et al., 2020) in their studies. However, Lak et al. (2020) pointed out the triple scales in their framework. Most strategies involved the neighborhood and city scale in their research. We argue that overemphasizing one aspect or scale and overshadowing one or two others might not result in resiliency as expected. This is mainly because studying COVID-19 merely on one spatial scale is problematic since the mobility across various scales and dynamic cross-scale interactions would lead to the transmission of the virus (Helbich et al., 2021). In addition, planners should not overlook the macro levels, such as regional and national scale, since nowadays, cities are increasingly interconnected due to globalization (Kummitha, 2020), which would negatively influence controlling the spread of viruses.

The framework introduced in this study help urban designers, planners, scholars, and policymakers have a more precise and comprehensive picture of resilient and anti-virus cities in the face of pandemics. In addition, the principles help policymakers adopt better measures to improve cities' resilience on different scales. By achieving a clearer perception of the components of resilient cities and their spatial scales, decision-makers can better focus on policies that increase cities' adaptive capacities and prevent virus spread during pandemics. As a result, the cities' economy and civil life would be less affected. Moreover, adopting such measures would also lead to higher levels of resiliency against other disasters and chronic hazards. Thus, this study suggests that researchers, practitioners, and policymakers focus on the presented framework and the principles in the four spatial scales to make better-informed decisions regarding resilience initiatives.

We recommend that future researches focus more on developing

design principles, standards, and disaster management protocols for commercial zones and public spaces in case of biological disasters such as pandemics to maintain the economy and vitality of cities and minimize the risk to the health and well-being of residents. Measuring the resilience of the built environment, such as buildings, neighborhoods, and urban public spaces, against pandemics is another topic that needs to be studied in future research. Finally, there is no unanimous agreement regarding urban and population density and its relationship with spreading infectious diseases. Thus, more data is needed from different case studies to show whether or not higher or lower density can directly affect the spread of a contagious disease.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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