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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Antivirus-built environment: Lessons learned from Covid-19 pandemic

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ABSTRACT

Before developing medications for an epidemic, one solution is to go back to the physical and built environment to reduce its impact. Epidemics have transformed our built environment because of the fear of infection. Consequently, architecture and urbanism after the Covid-19 epidemic will never be the same. Although the current global epidemic poses a challenge at all levels in the built environment, it will take time to develop an antivirus-enabled paradigm to reduce the potential risks or stop the virus from spreading. This study imagines what the antivirus-built environment looks like based on the lessons learned and the importance of designing a healthy and sustainable built environment. Many unanswered questions require further multidisciplinary studies. We aim to search for answers and learn from this forced experiment to add additional security layers to overcome future virus-like attacks.

1. Introduction

COVID-19 affects physical health most directly and has alarming implications for emotional and social functioning, the coronavirus has proven that a disaster doesn't fight with a known opponent. The enemy can simply be invisible with devastating consequences (Goniewicz et al., 2020; Pfefferbaum & North, 2020). The real world is fragile, and this virus is frighteningly causing massive disruptions across the globe (Budds, 2020; Saadat, Rawtani, & Hussain, 2020). Moreover, the digital world is fragile regarding cyberattacks. This could be a teachable moment to apply lessons from the cybersecurity world to protect our built environment during the COVID-19 pandemic. The coronavirus is quickly spreading and causes significant damage, mimicking the spread of computer viruses within a network (Kindervag, 2020). In the digital world, it is common practice to design and incorporate solutions that can help overcome virus attacks; for every new generation, a new security layer is added to ensure the ever-mutating computer viruses do not harm the digital structure (Ahlefeldt, 2020). Could policymakers, planners, and architects inspired by the digital world learn from its cybersecurity to make our built environment more resistant to the virus? Could we design and build our cities to stop the virus from spreading? If so, could we install an antivirus-built environment ready to help in the protection from coronavirus or other pandemics?

Infectious disease has already transformed our places through architecture, design, and urban planning. Previously, many trends in architecture and urbanism that we see today were derived from similar measures taken before to ensure the health, hygiene, and comfort of urban residents. Our built environment has always exhibited the capacity to evolve after the crisis (Chang, 2020; Dejtiar, 2020; Muggah & Ermacora, 2020). This study encourages the search for suitable design ideas, trends, and planning theories to provide the required protection from virus attacks and continue to add more layers in the defense system of our built environment. To cope with this pandemic, professionals in architecture, urban planning sectors, and design agencies have already switched their focus to visualize the post-pandemic era. However, there is inadequate research conducted to imagine how the antivirus-built environment would look. To address this gap, this study reviews architecture and urban story developments from the past centuries. We then review research areas affected by the COVID-19 pandemic and highlight their related questions. We then analyze the social distancing and quarantine as a design problem in the post-pandemic era. Subsequently, some lessons learned from the pandemic are presented to visualize and introduce the study's vision about the antivirus-built environment.

2. Historical background: dramatic change developments

During pandemics, the form has always followed the fear of infection, just as much as the function (Ellin, 1999). From interiors to city planning, our built environment is shaped by diseases. Previously, to minimize the risk of infectious diseases, people redesigned interior design, architecture, cities, and infrastructure. Considering historical

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events of the last two centuries, the architecture and urban story includes several developments.

2.1. Urban renewal

In the 14th century, the bubonic plague motivated the fundamental urban improvements of the Renaissance. Cities cleared overcrowded living quarters, expanded their margins, developed early quarantine facilities, and opened large public spaces. In the 20th century, infectious disease was one of the drivers of urban renewal. Modernist architects saw design as a cure to the sickness of overcrowded cities, where tuberculosis, typhoid, polio, and Spanish flu breakouts encouraged urban planning, slum clearance, tenement reform, and waste management (Chang, 2020; Lubell, 2020).

2.2. Sanitary reform

During the industrial era, cholera and typhoid influenced the sanitary reform movement. These epidemics contributed to developing water and sewage systems to fight the pathogens, eventually leading to a sanitary innovation and required the streets to be straighter, smoother, and wider to install underground pipe systems. Furthermore, the third plague pandemic in 1855 changed the design of everything from drainpipes to door thresholds and building foundations (Budds, 2020; Klaus, 2020; Wainwright, 2020).

2.3. Building and housing reform

The wipe-clean esthetic of modernism can be partially attributed to tuberculosis. The modern architectural designs were inspired by an era of purity of form, strict geometries, modern materials, and a rejection of ornamentation. Modernist architects designed these curative environments as cleansed (physically and symbolically) from disease and pollution. Beyond their esthetic appeal, these features embodied modernist preoccupations with the healing effects of light, air, and nature. These buildings included large windows, balconies, flat surfaces that would not collect dust, and white paint, emphasizing the appearance of cleanliness (Budds, 2020; Chang, 2020). Against this background, the current health crisis should develop our built environment to increase the security layers that help to prevent the spread of infections and diseases. In this context, there are multiple areas of research needed regarding COVID-19.

3. Research areas and questions

When the World Health Organization (WHO) declared the fast-spreading COVID-19 as a pandemic, citizens around the globe hastened to go home. This global pandemic significantly influenced our personal and professional lives and has a direct bearing upon the very foundations of urban planning and architecture theory and practice (Allam & Jones, 2020; Haleem, Javaid, Vaishya, & Deshmukh, 2020; Saadat et al., 2020). Consequently, the pandemic has led to questions of how architects and planners could present and install antivirus-related ideas or update the existing spaces, as well as at what stage can the pandemic affect our physical and built environment. To extend the scope of research needed from the academic community, Table 1 reviews certain required research areas affected by COVID-19 and highlights their related questions. Professional and extensive research is required on all levels and scales in these areas to prevent the virus from spreading. The answers to these questions could help in predicting the post-pandemic style and visualizing the required antivirus system.

4. Social distancing and quarantine as a design problem

In the absence of a specific vaccine to the coronavirus, physical distancing and the lockdown of the population are among the most immediate and precautionary measures to be taken. The WHO introduced these measures, which were practiced at both institutional and individual levels to become a universal mainstream strategy (Hishan, Ramakrishnan, Qureshi, Khan, & Al-Kumaim, 2020; Salama, 2020).

4.1. Potential transmission dynamics of COVID-19

Since most humans spend most of their daily lives inside the built environment, it is essential to understand the potential transmission dynamics of infection. As individuals move through the built environment, COVID-19 can be transmitted both by air and via direct and indirect contact. Viral particles can be directly deposited on surfaces or suspended due to natural and mechanical airflow patterns, or other sources of turbulence in the indoor environment (Cirrincione et al., 2020; Dietz et al., 2020; Horve et al., 2020). The WHO has prescribed maintaining an inter-personal distance of 1.5 or 2 m (about 6 feet) to minimize the risk of infection. However, more recently published studies support the hypothesis of virus transmission over 2 m from an infected person (Bourouiba, 2020; Setti et al., 2020). In addition, Oklahoma State University researchers simulated different environmental and movement conditions to see if a six-foot social distancing policy is enough. Their results indicate this policy is enough if the ambient air is static (Oklahoma State University, 2020). Other factors and wearing protective clothes affect the transmission dynamics of infection. However, WHO is continuously changing and updating all the mentioned distances based on the latest information and researches conducted by professionals.

4.2. Design problem and challenges

Based on the potential transmission dynamics of COVID-19 and the required measures, several competitions, conferences, and leagues have been cancelled or postponed. The coronavirus has motivated authorities to restrict access to most public spaces and large shopping areas. This pandemic could fundamentally change the way they operate in the future and requires further analysis (Honey-Roses et al., 2020). Architects, planners, and built environment professionals are keen to examine many social and spatial implications to generate new patterns and configurations of use (Paital, 2020; Salama, 2020). Architectural and urban spaces, as they relate to infectious disease epidemics, are not only about quarantine based on immediate and precautionary measures but also refer to design and planning problems and challenges in all building types and urban spaces as illustrated in Fig. 1. The pandemic of COVID-19 has caused serious consequences that can be an opportunity to review individual and collective choices and priorities. Most architecture today shows evidence of how humans have responded to infectious diseases by redesigning our physical spaces. Thus, social distancing could change the design and planning process (Budds, 2020; Chang, 2020), specifically with the increased acceptance of distance learning, online shopping, and the cultural connection of online entertainment. The use of media for information sharing, and webinars for sharing knowledge and expertise have seen widespread adoption during the COVID19 pandemic (Chick et al., 2020; Goniewicz et al., 2020). Although new technologies can create additional difficulties, opportunities have emerged to apply innovative solutions to more smart and virtual world applications in the built environment. When we increasingly work from a remote location, learn and upgrade skills online and shop for necessities from e-commerce sites, we reduce the need of traditional physical spaces by virtual digital ones which can be accessed from smart devices (Goniewicz et al., 2020; Hishan et al., 2020; Papu & Pal, 2020). According to the affected lifestyles, the increased reliance on digital channels in the built environment may endure long after the pandemic and affect in every design and urban aspects. Humanity is facing a global crisis, perhaps the greatest of our generation. Many measures adopted during the emergency will become part of daily life,

Table 1
Post-coronavirus architecture and urbanism: Research areas and questions.

Scope	Research Areas	Research Questions
Post-pandemic urbanism	• Digital transformation and telecommuting • Centralization and decentralization • Density of cities • Walking, cycling, and public transportation	• The COVID-19 crisis has changed the face of many of our cities and questioned how we should manage urban life in the wake of a pandemic. Would the pandemic inspire more urban improvements? Can we design cities that reduce infections? Would the post-pandemic era generate new urbanism based on social distancing? More specifically, could COVID-19 be a catalyst for decentralization and walkable cities?
Post-pandemic public spaces	• Design, use and perceptions • Design and disease transmission • Street design and furniture • Shared facilities and services • Flexibility and transformation	• There is no doubt about how COVID-19 will impact future public buildings and spaces. However, how long will these impact and reflection last for future? What about their furniture materials, shared facilities and services? What is the future of commercial buildings? Can air-conditioned shopping malls continue? Will the pandemic teach us new lessons to incorporate into our public buildings and spaces designs?
Post-pandemic housing	• Housing layout • Space and density • Shelter and safety • Indoor air quality	• What is the future of our houses? Should they adapt to better accommodate workspaces? Should they be self-sufficient? Should our terraces, balconies, and roofs be planted? More specifically, could COVID-19 be a catalyst for healthy housing and sustainable buildings?
Post-pandemic office space	• Layout and design solutions • Working and waiting spaces • Shared facilities and services • Density in offices • Building heights	• What is the future of co-working spaces and open-plan offices? Could COVID-19 alter their design? Would they need new design criteria? What is the future of high-rise buildings? Can skyscrapers continue? What happens when nobody wants to use elevators?
Building and construction technology	• Modular construction • Prefabricating standardized components • Lightweight and adaptable structures • Artificial intelligence	• What is the future of construction strategy? Could COVID-19 alter its techniques? Should we adopt a more modular construction strategy? If so, will the future witness more prefabricating and standardized components? Could the pandemic speed up the digitalization and automation of our cities? Will our smart devices control everything around us?

To date, these are some of the questions highlighted by the current pandemic, and we are currently uncertain about the answers. The answers to these questions are closely linked and remain a subject of significant research in the field during the global pandemic or through future events with similar impacts.

changing habits, and behaviors, they may be a positive or negative intervention in architecture and urban planning approaches.

While there are many potential impacts of COVID-19 on built environment, our focus in the following points is on how post-architecture may change. Although social distancing and quarantine measures are extensively adopted as the first preventive measure, other factors increase the risk of contracting the virus, as discussed below.

Population density. In our current health crisis, certain densely populated cities have proved to be particularly vulnerable to the risk of infection (Chang, 2020).

Household size. A big household, large, or extended families will have a higher chance to bring the virus home (Saadat et al., 2020). This will need special consideration in design solutions to prevent infection.

Social distancing level. Working from home might reduce social contact but is only available to some people focused on jobs linked to a higher socioeconomic status. Moreover, stay-at-home regulations would be more than a challenge for those who live in smaller and crowded houses or without outside spaces (Saadat et al., 2020).

Shared facilities. Shared housing includes a broad range of settings with special considerations. People living and working in this type of building might have challenges with social distancing to prevent the spread of COVID-19 (CDC, 2020).

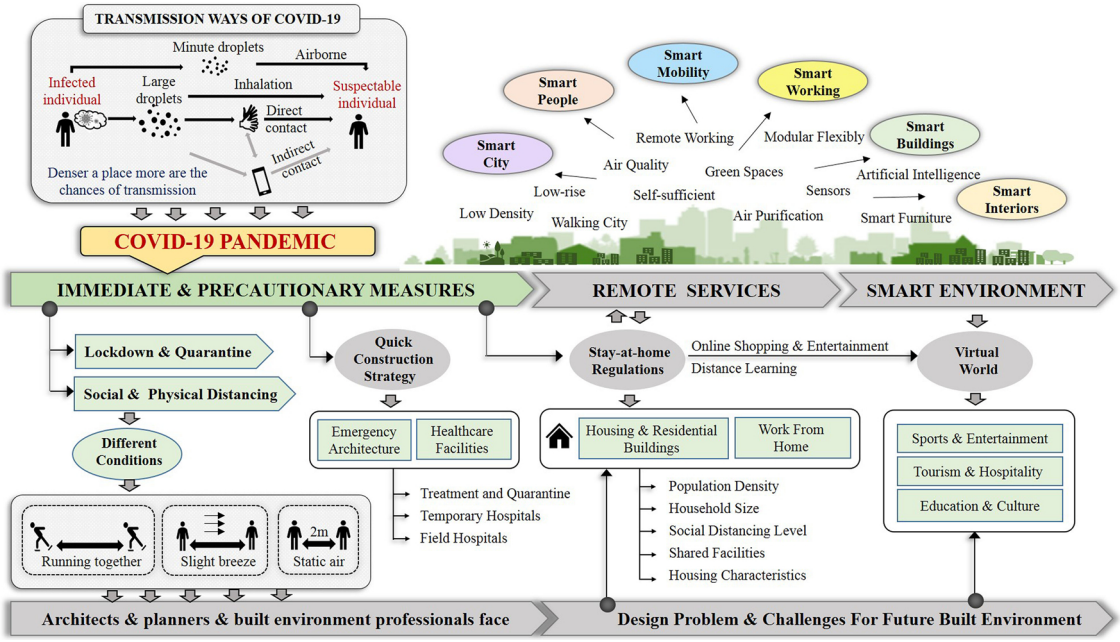

Fig. 1. Social distancing and lockdown reflections and their links to the variables under research.

Housing characteristics. With a stay-at-home attitude essential to the COVID-19 response, housing characteristics take on added importance in people's lives (Schellenberg & Fonberg, 2020). Extended time indoors could raise various challenges in the design of post-pandemic housing. Because we are forced to stay and work from home, post-pandemic house and office spaces will witness a great transformation because we will be more aware of the functionality of our homes and workspaces in an interestingly new approach. Some of these transformations are reviewed in following sections.

4.2.1. Post-pandemic housing

The pandemic has brought a greater sense of appreciation for our homes. People need houses that can effectively provide social isolation and offer protection from viruses and infections. The expectation is that even after the quarantine period, more people will work from home. Consequently, the future of home design might change (Dejtiar, 2020; Kashdan, 2020; Priday, 2020). Several studies have reported a direct association between crowding and adverse health outcomes. The WHO suggested the characteristics of healthy housing. High density could lead to unhygienic conditions and the spread of several communicable diseases. Crowding increases the risk of volatile infections and droplet-transmitted infections (Capolongo, Rebecchi, Buffoli, Letizia, & Carlo, 2020; World Health Organization, 1988). If possible, the current pandemic makes a strong case for completely detached housing with a reasonable amount of surrounding garden space, enhancing better facilities for social distancing and producing food, and the healing effects of light, air, and nature. Perhaps, quarantine is the best time to get to know more about indoor gardens, even in the case of multi-story buildings (Makhno, 2020; Wainwright, 2020). For multi-story buildings, contact with other residents in shared areas is unavoidable. The future should, therefore, focus on the touchless experience from the front door to the apartment door itself (Kashdan, 2020; Priday, 2020).

Regarding layout and design solutions, post-pandemic housing might introduce more partitions between departments and could be the end of open-plan spaces. The building might have wider corridors and doorways, and many more staircases, leading to changes in the building code and design strategies. Ensuring flexible and adaptable spaces for all users can make housing more sustainable, able to adapt to changing needs and to changing lifestyles (Capolongo et al., 2020; Wainwright, 2020).

4.2.2. Post-pandemic office space

Remote working consists of a relatively new mode of alternative work arrangements developed in the 1970s. Several firms have been adapting their measures as the spread of Covid-19 increases (Belzunegui-Eraso & Erro-Garcés, 2020; Papu & Pal, 2020). Even firms that were resistant to the concept of remote working have been forced to allow working from home. However, working from home all the time is not for everyone; many will want to return to their physical offices. As the pandemic continues or remote working becomes the new norm, office space might have to be altered to create greater spacing and fewer seating options (Marr, 2020; Molla, 2020). Based on this transformation, the density in offices might probably change and firms will not need more space because of work from home policies. Consequently, high-rise buildings would become more expensive to build and become less efficient. Depending on how productive remote work proves to be in this pandemic, it is hastening the shift from structured office environments to more flexible, virtual, and home-based work arrangements, which could mean a reversal of the open-office trend and the search for better other natural ventilation and healthy design options (Alter, 2020; Muggah & Ermacora, 2020). Regarding cleaning policies, certain firms could even use ultraviolet germicidal irradiation to deeply disinfect offices at night or meeting rooms between uses; a practice that is increasingly common in hospitals to combat the spread of infection (Beggs et al., 2000; Kovach et al., 2017; Molla, 2020).

5. An opportunity to reset and reshape our built environment

While it is uncertain how much change will follow COVID-19, mechanisms increasing its spread will not be forgotten or ignored (Priday, 2020). The pandemic has highlighted the lack of how we manage our built environment and presented certain lessons from this forced experiment. In this context, how should architects, planners, and policymakers react and learn? Beyond helping to design medical spaces limiting the spread of infections (Acuto, 2020; Betsky, 2020), the pandemic will allow them to reset and reshape our built environment. However, the time to reset and reshape our built environment is now, and not after the next pandemic. This study analyzes the lessons learned based on two approaches, namely, look step back to nature and look step forward to advanced technology.

5.1. Look step back to nature

A key lesson that we are going to learn is the requirement to return to nature with its healing effects. Although the situation is still unfolding, the COVID-19 pandemic has already highlighted the importance of certain design concepts and reassessed fundamental assumptions in urban and architecture approaches.

5.1.1. Urban approaches

To accommodate work from home situations, we could even reexamine old urban typologies. Many urban approaches might increase the protection and defense system of our cities and avoid high density and overcrowding. Policymakers and planners should use the current crisis to review planning theories and, based on the results, they should take a step back in searching about how past cities are structured.

Expanding horizontally. During a pandemic, the human proximity of heavily populated cities poses further risks. The larger the population, the higher the concentration of COVID-19 in cities. Regarding the impact of social distancing, planners and architects might design according to expanding horizontally approaches with more available open spaces, which could be essential to prevent the spread of infections and diseases (Liu, 2020; Novakovic, 2020).

Fewer density cities. Because social distancing measures are essential to the containment effort, some have blamed the density of cities for the rapid spread of the infection and considered suburbs to be the safest places. Urbanization might take a step back to enhance villages and city suburbs, particularly with the increased acceptance of digital transformation (Makhno, 2020; Nicola et al., 2020; Wainwright, 2020). However, the impacts of higher density on social interactions and sustainability are still controversial issues (Mousavinia, Pourdeihimi, & Madani, 2019).

Decentralization. The pandemic highlights the importance of distributing smaller units such as health facilities, schools, and services across more of the urban tissue and strengthen local centers (Alter, 2020; Wainwright, 2020). As more and more e-commerce models, the shopping malls may eventually lose their aspirational value, we would have to remodel traditional market in mixed use neighborhoods (Papu & Pal, 2020). In addition, the decentralized network of smaller green spaces will make it easier for residents to breathe nature that has important physical and mental health benefits (Velarde, Fry, & Tveit, 2007). Decentralization approach could probably encourage horizontal expansion, requiring a review of planning theories to maintain sustainable development and adequate city planning (Madanipour, 2001; Taylor, 2000).

Urban farming. The notion of a self-sufficient community is the answer to protect the environment and ecological systems (Ali, Dom, & Sahrum, 2012; Martinez et al., 2010; Priday, 2020; Tait, 2003). It is urgent to rethink how land is used with landscapes and urban farming integrated approaches (Proksch, 2017). Urban farming has been recently growing, strengthening self-sustaining communities to become more resilient to the epidemic. Farming could improve food security

Table 2
Construction strategies used in healthcare systems during the pandemic. The authors after (Allam & Jones, 2020; CNA, 2020; Constable, 2020; Hatcher, 2020; Lubell, 2020; Mcginn, 2020).

Strategy	Example	Description
Modular construction	Vic hospital, Melbourne, Australia	A semi-permanent resuscitation unit has been built at the hospital. The unit comprising a prefabricated semi-containerized two-story COVID-19 specific-purpose hospital in its car park.
	Leishenshan hospital, Wuhan, China	A 1,600-bed hospital constructed on a parking lot from prefabricated modules placed into steel skeletons above concrete foundations.
	CURA prototype, Milan, Italy	Italian architect and professor designed intensive-care pods within a shipping container called CURA. The pods connected by inflatable corridors and fitted with biocontainment systems.
Adaptive reuse	Temporary hospital, Javits Center, New York	New York City's Javits Convention Center turned into a 2,910-bed temporary field hospital for COVID-19 patients
	The Nightingale Hospital, London, UK	Excel Exhibition Centre turned into a 500 -bed hospital equipped with ventilators and oxygen with the capacity increased to fight COVID-19.
Lightweight architecture	Inflatable emergency hospital, Pachuca, Mexico	The hospital designed to be the quickest response to an immediate care center. A 1,000-square-meter structure prepared to see up to 80 COVID-19 patients daily.
	UCSF Medical Center, San Francisco Bay, USA	The hospital sets up two outdoor tents to prep for possible influx of COVID-19 patients which employed as triage and emergency room extensions, waiting and treatment areas.

and nutrition, reduce climate change impacts, and lower stress. In this context, vertical and urban gardens should be flourishing (Ahlefeldt, 2020; Chandran, 2020; Kashdan, 2020; Muggah and Ermacora, 2020). Urban farming integrated approaches have been implemented using the latest designs and technologies with other architectural approaches (Dmitriy & Alevtina, 2019).

Fewer cars, more cycling, and walking. One of the key lessons that we are going to learn is having a network of cycling and walkable streets. Walking, as a primary mode of transportation and physical activity, has proven both environmentally friendly and beneficial for residents' physical and mental health (Dreessen, 2020; Zhou, He, Cai, Wang, & Su, 2019). In the fight against infection and maintaining social distancing, cities should offer more safe paths and small roads for walking and micro-mobility than depending only on mass public transportation. While considered a good environmental solution to reduce pollution, public transportation is not ideal during a pandemic as it might contribute to the spread of diseases among users (Campisi, Acampa, Marino, & Tesoriere, 2020; Constable, 2020; Gonzalez, 2020; Musselwhite, Avineri, & Susilo, 2020). The pandemic has emphasized that efficient multi-modal transport is more robust and thus essential to sustainable growth. No single mode of transport is in the long run superior (Capolongo et al., 2020; Hishan et al., 2020). Streets might need to be re-designed to meet multi-modal transport needs, which succeed in transforming streets to become healthier, safer, greener, and more livable (Honey-Roses et al., 2020).

5.1.2. Architecture approaches

Previously, many architecture approaches were related and increased the healthy spaces of our buildings and enhanced sustainability.

Self-sufficient strategies. In future, a high priority will be placed on self-sufficient buildings and lifestyles (Ali et al., 2012; Greer, 2009; Priday, 2020). In addition to all the energy-efficient strategies with heating and cooling systems, architects might inspire additional methods of thinking concerning water supply and food production.

Refocusing on green spaces. We require physical interaction with living plants for our mental health, and to grow what we eat to reduce risk, specifically during self-isolation (Constable, 2020; Makhno, 2020). Consequently, planting our gardens, terraces, and implementing green roof systems have multiple advantages for sustainability (Hui, 2011; Specht et al., 2014; Thomaier et al., 2015) and can solve most of the self-isolation problems. The challenge for the roofs is to consider them as the buildings' fifth façade to be the place of green roofs. However, during the design process, green roofs designed for food production might require additional calculations and requirements (Abd-Elhafeez, ELmokadem, Megahed, & El-Gheznawy, 2016; EL-Gheznawy, 2016).

Low-rise buildings. High-rise buildings were designed to organize as many people as possible in one place. During a pandemic, it is necessary to reduce contact with everything in multi-story buildings such as elevators, elevator buttons, door handles, and surfaces (Capolongo et al., 2020; Makhno, 2020). This new fear of infection and fear of being trapped in the elevator should take future consideration in post-pandemic architecture with other psychosocial problems.

Better air quality. After forced self-isolation and spending more time indoors, an approach to improving health through strategies such as greater natural light, improved ventilation, fewer toxic substances, and incorporating plants and other natural materials is necessary (Constable, 2020; Lubell, 2020). In this context, it is critical to design buildings with skylights, large windows, rooftop terraces, balconies, and courtyards to avoid sick-building syndrome and enhance air quality (Guy & Farmer, 2001; Roaf, Crichton, & Nicol, 2010).

5.2. Look step forward to advanced technology

To receive the maximum benefits from the previous approaches, the antivirus-enabled paradigm requires advanced technology in the construction sector and a tool to quicken the pace of digital transformation. This approach requires using techniques outside the mainstream to secure our built environment by running alternatives, exploring, and inspiring new ways of constructing more sustainable and safe buildings.

5.2.1. Construction strategy

The post-pandemic emphasizes the importance of look step forward of the innovations in construction techniques that speed the creation of emergency architecture.

The COVID-19 pandemic represents an unprecedented challenge for healthcare systems internationally. Medical facilities and their human resources are usually overwhelmed (Robbins et al., 2020; Scarfone et al., 2011). The sheer scale of the pandemic puts enormous stress, most countries built field and temporary hospitals in a matter of a few weeks or reused other building types and spaces to add thousands of beds. Table 2 reviews the most construction strategies used in constructed additional healthcare systems to prevent further COVID-19 infection.

Modular construction. Increasingly popular before COVID-19, the modular construction strategy is effective to face pandemics or natural disasters and to create less expensive and more quickly constructed buildings (Smith & Quale, 2017). It is important for meeting health services' diverse requirements with prefabricated standardized components. These components could help buildings adapt to requirements or enlarge their spaces for treatment and quarantine (Hatcher, 2020).

Adaptive reuse. This strategy is a sensitive and sustainable approach to create emergency facilities. During a pandemic, sports

facilities, parking lots, and other buildings are converting into medical facilities and temporary hospitals. There will be a requirement for more efficient, effective, and flexible reuse plans for future crises (Lubell, 2020). This strategy is beneficial when integrated with other advanced technologies in the construction sector.

Lightweight and adaptable structures. When responding to the pandemic, lightweight and adaptable structures are often preferable for their speed and portability. Designers are developing and assembling these temporary structures to create field hospitals that can be easily transported and erected for COVID-19 patients (Constable, 2020; Lubell, 2020).

Hygienic building materials. There will be a special effort to consider and think about every possible place within the built environment touched by people and the possibility of that being a source of infections. Like the modernists who rejected ornament in service of hygiene, contemporary designers are likely to use hygienic and antibacterial materials that can be easily sanitized (Kashdan, 2020; Molla, 2020). Post-pandemic architecture might apply more cleaning strategies based on new technologies. For applying a strategy based on nanotechnology, we should consider other potential risks associated with nanomaterials (Megahed, 2013).

5.2.2. Digital transformation

The global pandemic has forced us into an entirely new world and has increased digital transformation in all our activities. After the crisis, we will have entered a new digital normal. In a few months, the pandemic has offered virtual and augmented reality alternatives, which are expected to continuously increase (Gracy, 2020; Muggah & Ermacora, 2020).

Ability to work from home. As a lesson learned, this pandemic brought to light the possible reduction of air pollutant emissions by increasing expand remote working. During the quarantine, most people have been forced to work from home (Nakada & Urban, 2020). More consideration will be given to the arrangement of the workplace at home. The spatial organization will change. It will be a separate room with large windows, blackout curtains, and comfortable furniture. It will be technically equipped, and sound insulated (Allam & Jones, 2020; Capolongo et al., 2020). While working from home is a benefit many employees value and reduces pollution, the long-term impact is unclear and requires further investigation.

Artificial intelligence and touchless technologies. Automation, voice technology, and facial recognition-based in artificial intelligence could influence post-pandemic architecture. With 80 % of infectious diseases transmitted by touching polluted surfaces, touchless technology could become a new interface and remove the requirement for physically pushing or touching a surface. Post-pandemic principles search for more contactless pathways, such as lifts being called from a smartphone, avoiding the need to press any buttons, and doors to open automatically (Molla, 2020; Wainwright, 2020). These technologies could include other programs to both control space temperature and automatically clean it to kill harmful organisms, viruses, and bacteria. Although there is an added cost, it might be an amenity that will gain popularity to be integrated into future buildings (Kashdan, 2020; Makhno, 2020).

6. Discussion: antivirus-built environment

One positive impact of the current pandemic is the time it offers to the built environment professionals to reflect on past events and learn what can be improved for future responses (Goniewicz et al., 2020). Although pandemics have long been catastrophic, they have forced architecture and city planning to cope with it. Covid-19 might have similar effects on architecture and urban planning developments (Budds, 2020; Chang, 2020; Saadat et al., 2020). Life after the pandemic will never be the same; values, lives, and habits will change, and our architecture will change under that influence. In all these circumstances, we might enter a completely post-pandemic style in which form follows fear of infection. Cities are currently being tested to the extreme with the pandemic and multiple questions are arising in terms of how cities are planned and managed. Its impact is showing the extent to which each city can function, or not, especially during times of crisis (Lubell, 2020; Wahba & Vapaavuori, 2020). Our built environment is not designed or built to effectively help limit the effects of pandemics, such as the COVID-19 pandemic. However, we are learning fast and there are already lessons worth learning and remembering. The pandemic will not last forever, but our response to it will shape our future built environment (Ahlefeldt, 2020; Novakovic, 2020).

The significance of adding human health as one of the sustainability development goals can be seen through the current pandemic. From a conceptual perspective, adding human health as the fourth pillar to the overall definition of sustainability is a logical step (Hakovirta & Denuwara, 2020). Many architecture and urban approaches might increase the protection of our cities and avoid overcrowding. In normal times, there might be many attributes attempted by the built environment to achieve sustainability. The pandemic's influence in the densest areas raises questions about sustainable development and fundamental assumptions of past theories. However, the future is still unclear; perhaps we hope to see a shift towards a greener, smarter, and a more sustainable built environment. Alternatively, distance communication and digital transformation could change our long-term habits and dramatically cut traffic and pollution. What if we harnessed telecommuting and digital city strategy as a way of social distancing and to help employees and citizens achieve work-life balance? Based on the feasibility of working continuing remotely after the pandemic passes, our cities might require fewer spaces for highways and parking lots. In this case, we could recover these spaces for use as safe cycling and walking networks. It sounds utopic but this vision might encourage people to take their bikes to work and give more space to pedestrians (Gonzalez, 2020; Muggah & Ermacora, 2020). Post-pandemic design and planning strategies must reflect this change. The right design and planning strategies now could help to position our built environment in the post-pandemic era. However, there are many other social effects beyond the pandemic; however, the long-term impact is unclear, requiring further studies. Let us hope we do not encounter this scenario; however, if it comes again, at least we can understand the risks and be better prepared in the prevention and quickly react in mitigation.

As shown from the lessons and the complexity of the pandemic, it is no longer safe to solely rely on a strategy to protect our architecture and urbanism. Instead, we must install an antivirus-built environment that incorporates a multi-layered approach of protection into its defense system. Architects and planners should design our built environment such as to stop the virus from spreading by creating an antivirus-enabled paradigm. This paradigm must improve new tools, options, and strategies that are more flexible, holistic, and responsive to better address the pandemic response at all levels and scales from interior design to city planning. Based on the lessons learned from this crisis, Fig. 2 shows the proposed vision about how nature and advanced technology approaches help in visualizing antivirus-built environments to stop the virus from spreading. However, selecting the best antivirus strategy depends on many factors, posing new challenges to choose that could be used or planned as long-term reforms. We must be proactive, not reactive, and continue to update this antivirus-enabled paradigm and install new approaches within its framework. Many questions still require further multidisciplinary studies. This study does not present answers; it originates insights for areas where future research will be critically required to update the proposed vision.

The proposed vision in this study does not have an expiration date, when the Covid-19 pandemic ended, most of healthy architecture and urban approaches could be applicable to the pandemics to come. We could imagine all housing buildings as self-sufficient, independent and healthy neighborhoods and making smart use of the available technologies. It is crucial to make urban areas more resilient to emergencies

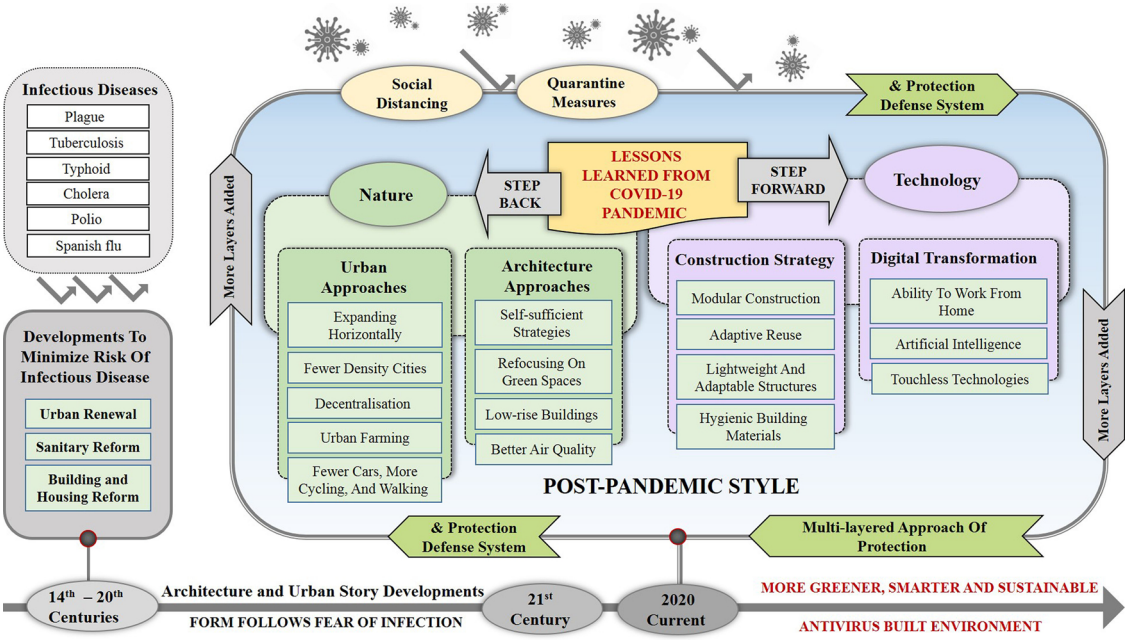

Fig. 2. The proposed vision about the future of the antivirus-built environment.

response, to face epidemics and other possible future emergencies of every kind.

7. Conclusion and outlook

There is no end in sight to the COVID-19 pandemic, but it has helped us predict what post-pandemic architecture and urbanism might look like. Although we are not going to overhaul how we have been building architecture and cities before, based on the current circumstances and emergency measures, we should review our design strategies and planning theories. We could more effectively use healthy design and planning strategies to face pandemics and create a less pullulated, more sustainable architecture, and urbanism in general. Moreover, if we harnessed the security layers not only to prevent ever-mutating virus attacks but a healing approach that could be implemented in the post-pandemic era, it could help build a sustainable environment. Therefore, is this transformation in our physical and built environment a temporary reaction or the new normal? With spread of the COVID-19 pandemic, additional questions will undoubtedly arise, and additional security layers should be added to update an antivirus-enabled paradigm. This study does not present answers; it only provides insights for areas where future research will be critically required to extend the scope of research required. Based on the lessons learned from this crisis, this study introduces a vision about the required antivirus-built environment that can be updated to stop the virus spreading or mitigate its impacts. However, selecting the best antivirus strategy depends on many factors such as the abilities and capabilities of each community and environment. The global pandemic has highlighted the limitations of how we manage our built environment regarding how we should design, build, and run our built environment; however, it has given us a chance to learn. Nevertheless, certain questions remain such as will we regard these unique lessons? If so, we should think more specifically about the benefits of this forced experimentation and implement further developments to select which could be used or planned as long-term reforms from a transformative viewpoint. In this context, the pandemic increased the requirement for policymakers, planners, and architects to think more out of the box, trying to reshape our physical spaces, and reset the existing build environment or develop more ideas to face future virus attacks. These changes give us a glimpse at how our cities could change for the better, and the worse, in the long-term. However, it is too early to judge how responses to COVID-19 will affect design and urbanism theories. These results call for urgent efforts to further explore our built environment and not wait for another pandemic to serve as a reminder. This approach must be parallel to other sustainable approaches embracing not impinging natural resources and not harming our environment. If we can manage that, our present architecture and cities will continue to serve us well. However, the post-pandemic era will see multiple challenges that require a better understanding of COVID-19 and its socioeconomic effects on society. The future remains uncertain and thus future multidisciplinary studies are required.

Declaration of Competing Interest

The Authors declare that there is no conflict of interest.

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