Chapter

The Role of Architecture and Urbanism in Preventing Pandemics

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Abstract

This chapter aims to assess the historical role of architecture and urbanism in the prevention and mitigation of pandemics and the place it may occupy in future international strategies. During COVID-19, the contemporary healthcare system response to pandemics showed its limits. There must be investigated a more interdisciplinary answer in which the role of the built environment in the One Health should be clarified. Since the 19th century, the built environment traditionally occupied a decisive role in mitigating pandemics. The war against tuberculosis led to the Hygiene movement which set the principles of the Modernist architectural and urban movement. With the discovery of antibiotics, the medicine emancipated from architecture. In the absence of health implications, the social and environmental counterreactions to the Modernist movement led to the Green Architecture, New Urbanism or Urban Village movements. After the last decades warnings about future pandemics, some of the present COVID-19 scientific findings have notable impact on the built environment design: pollution, green areas, urban population density or air quality control. Finally, the chapter analyses architectural and urban measures for preventing and mitigating future pandemics: air control, residential approaches, public spaces, green areas design, working, transportation and mixed neighborhoods.

Keywords: architecture, urbanism, green buildings, built environment, pandemics, health, environment, ecology, COVID-19, SARS-CoV-2

1. Introduction

This chapter aims to reveal the role of architecture and urbanism in the prevention and mitigation of pandemics. Although since the 19th century the built environment traditionally had a decisive role in mitigating pandemics, such as tuberculosis, the emancipation of medicine, after the discovery of antibiotics, gradually excluded architecture and urbanism from the strategies against pandemics. In the context of COVID-19, there are relevant reasons for an interdisciplinary scientific approach of pandemics including the built environment and for a reevaluation of the future international strategies.

2. The limits of the contemporary healthcare system response to pandemics

In the second half of the 20th century, a complex set of measures was set in place that successfully fought against pandemics. Pharmaceutical interventions brought substances such as antibiotic drugs against tuberculosis or such as vaccine products against influenzas. In 1997, International Coordination Group (ICG) was established by the World Health Organization (WHO) "to manage and coordinate the provision of emergency vaccine supplies and antibiotics to countries [1]". Unfortunately, although existing influenza vaccines are among the most effective protections and strategic stockpiles for several influenza types are gathered, they are ineffective against new strains. Developing and distributing a new vaccine takes several months, delaying the pharmaceutical response. As for antibiotics, WHO started, since the 1990s, to strengthen the surveillance of the drug resistance for the tuberculosis.

Lack of pharmaceutical means, non-pharmaceutical interventions "should be put in place, at the early stage of a pandemic [1]". The foreseen interventions included hygiene, social distancing, using facemasks and schools' closures. The non-pharmaceutical interventions were established as part of the international response interventions: anticipation, early detection, containment, control and mitigation as well as elimination or eradication. These measures were regulated, since 1969, by the International Health Regulations that aimed to "prevent, protect against, control and respond to the international spread of disease". Events that might have international consequences were supposed to be promptly reported by the states to WHO for assessment.

The COVID-19 pandemic showed the limits of the existing healthcare system strategies. By the end of 2020, lack of adequate response, the pandemic led to a dramatic health impact, with more than 1.5 million deaths by December 2020 [1], to a huge social disruption and an economic result that brought to the biggest global recession since the 1930s Great Depression.

Without an effective treatment for COVID-19, governments adopted the 19th century traditional measures concerning people and the built environment. The 2020 approach was contrary to the WHO politics of 2018, which stated that "many traditional containment measures are no longer efficient" and that "measures such as quarantine, for example, once regarded as a matter of fact, would be unacceptable to many populations today [1]". People oriented measures in 2020 addressed individuals, like hygiene or wearing face masks, or were related to contacts with people, like the social distancing (or physical distancing), curfew, isolation, quarantine and confinement (lockdown). Building oriented measures were also adopted by interior air control through ventilation.

The COVID-19 pandemic brought into attention other **non-pharmaceutical methods** that may prevent or mitigate the effects of pandemics. One of the directions concerns the environmental approaches. As for the role of the built environment in fighting against pandemics, scientific studies undergone during 2020 concerning pollution, urban heat islands, land use, green areas, urban density and interior air quality suggest that the buildings and the built environment may play a decisive role in the international strategies against future pandemics.

3. The One Health system response to pandemics and the role of the built environment

In the 1980s, after increased outbreaks of zoonoses, human healthcare system became aware of the benefits in approaching human and animal diseases together with the unifying concept of One Medicine [2]. In the 1990s, due to the alteration of the ecosystems which led to new ways of diseases spread, the role of the environment in human health became relevant [3]. During the decade of the 2000s, the unification was extended to the humans, animals and environment resulting the One Health system in the 2000's [4, 5]. A broader spectrum of professions was brought together, gathering **veterinarians, ecologists, economists, sociologists or wildlife managers**.

The 2010 decade brought an increased awareness of the urbanization risks for pandemics. The approaches were quantitative and focused on the **overlapping of habitats, the heat that provide high-risk habitats for animals and the high density of people**. As for the building health, there is also consistent literature about its role in supporting physical, social or psychological health. One of the key aspects is the indoor environmental quality, focused on the **air quality**.

Despite these advances in understanding the role of the built environment in human health, by the end of 2020 the was still not international strategy that included buildings and the built environment in the fighting against pandemics.

4. The historical role of the built environment in pandemics before the advent of antibiotics

Until the arrival of antibiotics in the middle of the 20th century, the main historical methods against bacterial pandemics were limiting the contacts between individuals through **isolation, quarantine and confinement** (**lockdown**) and, from the 19th century, the architectural and urban measures concerning air quality and sunlight.

In the case of leprosy, containment led to the appearance of the first dedicated architectural program, the leprosarium. The measure was common in Medieval Europe [6], although "less uniform and prescriptive [7]".

Plagues were the deadliest pandemics. The 1346–1353 Black Death supposedly killed up to half of Europe's population [8]. They pushed to a diversification of measures aiming the limitation of contacts between individuals, such as isolation, quarantine, confinement, the use of plague mask and the introduction of the medical passport. They also led to dedicated constructions, such as the 27 km long, six feet tall, Plague Wall in the French Vaucluse mountains traced in 1721 [9, 10]. Since the 19th century, plagues impact diminished.

The tuberculosis, "the white plague", took the relay, with a peak mortality rate in Western Europe in 1800 [11]. Tuberculosis deaths counts for 45% between 1790 and 1796 in Bristol, 33.2% of deaths between 1751 and 1778 in Marseille [12] and for 25% of death between 1810 and 1815 in New York City [13]. In 1900, it remained the third cause of mortality after cardiovascular diseases and influenza–pneumonia in the US [14].

In France, the backbone of the fight against tuberculosis was the **Hygiene movement** in which public health was supposed to scientifically guide political decisions, architecture and urbanism. The movement started in the 1820s, continued with the creation of the Hygiene Commissions (1848) and of the Commission for Unhealthy Housing (1950) [15] and reached its peak in the urban renewal during the Haussmann period as Seine (Paris) prefect (1853–1870). The French capital applied the hygiene reform at the largest scale ever seen: **sewage, wastewater treatment, waste removal, air circulation inside and between buildings, sunlight**.

Hygiene movement derived principles definitively marked architecture and urbanism. The sunlight that kills bacteria imposed the sanatoriums as general architectural models, with vast windows stretching from one side to the other of the room and terraces for sun baths. Sunlight and ventilation at the 45th parallel north are the reason for imposing distances in between buildings greater than the building height.

At the turn of the 20th century emerged the British **Garden City movement**, started with the Ebenezer Howard's 1898 book, republished in 1902 as *Garden Cities of To-morrow*. In Germany and Switzerland appeared the *Lebensreform* (Life Reform) movement.

The turn of the 20th century brought the first *International Congresses on Tuberculosis*: Berlin (1899), London (1901), Paris (1905). The *First International Congress for Sanitation and Housing Health Safety* was held in Paris (1904). The congress report correlates population density and health. The European research of the French dr. Samuel Bernheim concludes that "The tuberculosis mortality is proportional to the housing density; the danger of infection is all the greater when the residents are more cramped in their housings [15]".

The hygiene measures led to a decline of tuberculosis and, at the turn of the 20th century, mortality was reduced at half in Paris between 1872–1900 and 1901–1925 periods [12].

The 19th century Hygiene movement marked the Interwar modernist architecture. Architect's **Le Corbusier** *Five Points of a New Architecture* are derived from Hygiene movement theories. The **house on *pilotis***, reinforced concrete columns raising the house from the ground, allows aeration. The **roof garden** is inspired by the sanatorium sunbath terraces. The **free plan** allows the liberation from being the "slave of the load-bearing walls". The **horizontal window**, "essential goal of the house", which "runs from one end to the other of the façade" is directly taken from the 19th century recommendations. The **free façade** in front of the columns is a "lightweight membrane made of isolating walls or windows". Modernist urbanism is synthesized by the Le Corbusier architect book *Athens Charter* (1933) and the Josep Lluís Sert architect *Can our cities survive?* (1942). Hygiene movement principles were employed, emphasizing lighting and sunlight, light-oriented buildings and air circulation inside and between buildings.

One year later, in 1943, the discovery of the streptomycin antibiotic brought the first effective treatment for tuberculosis. The health strategies against bacterial pandemics no longer needed the support of architecture and urbanism.

5. Architecture and urbanism after the emancipation of medicine

As human health ceased to be an architectural and urban issue, Modernist movement, that promoted air, sun and light, was judged by social and environmental concerns determined by the functional segregation and the automobile-based traffic. In 1972 was symbolically declared the death of the modernist movement with the demolishment of a 1955 modernist US housing planned according to the principles of Le Corbusier [16].

The environmental counterreaction appeared in the late 1960s with the **green architecture**, as a reaction to the suburban sprawl and to the energy crisis. Different approaches are green city, sustainable city, eco city, zero & low carbon cities, zero energy city, livable city, compact city, smart city or resilient city. They concern pollution, carbon emission, energy, water, waste management and recycling, green-space ratios, forests and agricultural land loss.

The counterreaction to the social environment led in the US to the **New Urbanism** movement, in the 1980s. It emphasized mixed-use neighborhood and encouraged walking and bicycle transportation [17]. At the same time emerged in Europe the **Urban Village** movement that also promotes mixed use zoning aiming for partial self-containment by combining working, leisure and living, leads to medium-density housing, encourages walking and bicycling as well as public space encounters.

6. Health engaged architecture and urbanism certifications

At the end of the 20th century were introduced building certification systems. At the architectural level, green building certifications of the 1990s concerned health issues, such as the 1990 Building Research Establishment's Environmental Assessment Method (BREEAM) and the 1993 Leadership in Energy and Environmental Design (LEED). They relate to **indoor air quality, ventilation, interior lighting and daylight, thermal comfort, acoustic performance and the quality of views**.

More health-oriented certifications started in the 2010s with the 2012 Fitwel, a joint initiative led by the US Centers for Disease Control and Prevention (CDC) and General Services Administration (GSA), or WELL Building Standard from the International WELL Building Institute, launched in 2014.

At the urban scale, healthy cities topics are only generally addressed by initiatives such as the WHO European Healthy Cities Network or the Urban Low Emissions Development Strategy (Urban LEDS). As for the LEED for Neighborhood Development, it repeatedly addressed health as a main issue: preferred location within existing cities to **avoid the health consequences of sprawl**, reduced motor vehicle use to reduce pollution, **promote bicycling**, **walkable streets** "to improve public health", **compact development**, **access to public space** and **connected community** "to improve public health", access to recreation facilities to "improve public health by providing **recreational facilities close to work and home**", **neighborhood schools** "to improve students' health by encouraging walking and bicycling to school [18]".

7. The last decades warnings about future pandemics

According to a 2008 *Nature* paper, emerging infectious diseases, dominated by zoonoses, "are increasing significantly over time", with "the emergence of 335 infectious diseases between 1940 and 2004" and "reflecting a large number of drug-resistant microbes [19]". The most commonly cited reasons for this increase are the environmental issues, such as overlapping of habitats due to the agricultural intrusion in the ecosystems [20–22] or the global warming [23, 24] and urban heat islands [25, 26].

During the last decades, there was such concern about the zoonotic diseases impact that the COVID-19 pandemic seems the precise illustration: "**Virtually every expert on influenza believes another pandemic is nearly inevitable, that it will kill millions of people, and that it could kill tens of millions**—and a virus like 1918, or H5N1, might kill a hundred million or more—and that it could cause economic and social disruption on a massive scale. This disruption itself could kill as well. Given those facts, every laboratory investigator and every public health official involved with the disease has two tasks: first, to do his or her work, and second, to make political leaders aware of the risk. The preparedness effort needs resources. Only the political process can allocate them [27]."
In the 2016 United Nations *Environment Programme* report about the "Emerging Issues of Environmental Concern", zoonosis arrived second out of the six issues [28]. In 2018, WHO estimated that "another influenza pandemic is inevitable but unpredictable [1]".

8. COVID-19 scientific findings with impact on the built environment design

The inevitable came with the COVID-19 pandemic. It led to an important allocation of resources in scientifically addressing the pandemic. Although the most notorious studies concern vaccines and antivirals, other research directions regard non-pharmaceutical measures aimed to prevent or mitigate pandemics. As in the 19th century, the implementation of some of these findings needs a **dedicated built environment approach**.

8.1 Pollution

Air pollution was already subject to studies that proved the effects on human health, such as respiratory diseases or lung cancer [29]. The correlation between road traffic, pollution and health has been associated with heart disease mortality [30].

Studies undergone in 2020 almost unanimously found that the relationship between air pollution and the COVID-19 led to a "large increase [31]" in the US, clear increases in the Netherlands [32], to a "significant relationship [33]" in China, "aggravating [34]" in a study on nine cities form India, China, Pakistan, and Indonesia and "increase vulnerability [35]" or positively associated with higher fatality rates [36] in Italy.

8.2 Green areas

Pre-pandemic studies already concluded not only that "the percentage of green space in people's living environment has a positive association with the perceived general health [37]" but also "consistent negative association between urban green space exposure and mortality, heart rate, and violence, and positive association with attention, mood, and physical activity [38]".

In the context of the COVID-19 pandemic, studies interpreted the distribution of green areas as part of the environment role on the infection's risks [39]. Green spaces are also interpreted as a barometer for health inequity [39]. The green spaces help regulate the heat islands [40], generally considered as a zoonotic pandemic aggravating factor. There are studies that show how suburban forest fragmentation led to increased human disease risk.

8.3 Urban population density

Studies carried over time aimed to determine the correlation between population density and pandemics. For the 1918 Spanish flu, in England and Wales, research found "30–40% higher rates in cities and towns compared with rural areas" but "no association between transmissibility, death rates and indicators of population density and residential crowding [41]". A research on India stretches that districts with a lower density experienced lower rates of population loss [42]. A US research revealed "the positive correlation between population density and influenza mortalities [43]" although another paper finds no significant correlation between population density and transmissibility measured by the reproductive number (R) [44]. As for Japan, a paper concluded that "lower morbidity in the towns and cities is likely explained by effective preventive measures in urban areas [45]."

Other researchers investigated the correlation between population density and epidemics of tuberculosis or avian flu [46–49]. Paper also discussed on the impact of urban form and land use on the transmission of vector-borne viruses [50].

During the COVID-19 pandemic, most of the researches consider increased population density as a health risk. Papers in Japan concluded that "the correlations between the morbidity and mortality rates and population density were statistically significant [51]" or "the population density was shown to be a major factor [52]". In India, there was a "moderate association between Covid-19 spread and population density [53]". In Algeria, "there is a strong correlation [54]". In Turkey, "population density mediated the effect of wind speed (9%) on the number of COVID-19 cases [55]". US studies show contradictory results which must be further analyzed through different criteria. A paper concludes that "counties with greater population density have greater rates of transmission [56]". Some concluded that denser locations more likely to have an early outbreak but did not found evidence that linked the population density to the COVID-19 cases and deaths [57]. Another study pointed that "county density leads to significantly lower infection rates and lower death rates [...] possibly due to superior health care systems [58]".

Those conclusions must be correlated with studies that include income, education or health care systems [36, 59]. A study involving more variables was realized in Italy, showing that population density was not statistically significant but, instead, car and firm density were positively associated with higher fatality rates [36].

These researches are limited though by the ability of collecting geolocation data. In the US and in the EU, gathering spatial data about people movements was neither intended by the governments nor embraced by citizens' free participation [60].

8.4 Air control

Respiratory route transmitted diseases can spread either by droplets or by aerosols (suspensions in air of finer particles). By 2020, "virtually all infectious disease dynamics models on influenza have thus far ignored aerosol-transmission [61]".

Research conducted during the COVID-19 pandemic showed that aerosols could be one of the most dangerous way of transmission in the interior spaces. A paper concluded that "virus could be detected in aerosols up to 3 hours post aerosolization [61]". The badly ventilated rooms present the highest risk as an article on a Wuhan Hospital shows that the highest virus concentration was found in the toilets [62].

A 2020 research shows that **3 air changes per hour**, which is common in most countries legislation, "generated reductions in expected outbreak sizes that would normally only be possible with a substantial **vaccination coverage of 50–60%,** which is within the range of observed vaccination rates in school settings [63]".

Studies show also that recirculating the air without proper filtration presents a potential risk. According to the study of a closed restaurant in Guangzhou, published on 2 April 2020, "droplet transmission was prompted by air-conditioned ventilation" and therefore the virus might have traveled through the central HVAC system [64]. The finding was confirmed by the April 2020 statement of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHARE) that "infectious aerosols can be disseminated through buildings by pathways that include air distribution systems and interzone airflows [65]".

9. Architectural and urban measures in mitigating pandemics

During the COVID-19 pandemic, the established principles were opposed to contrary solutions:

- the need for creating public spaces for encounters was replaced by social distancing
- the dense city paradigm, as opposed to the urban sprawl, posed virus transmission problems
- encouraging public transport was replaced by the individual transportation.

Based on the scientific findings during the COVID-19 pandemic and based on previous experiences, architecture and urbanism can provide solution with the design of the buildings and of the built environment:

- interior spaces: air quality
- residential: middle density and the intermediate housing
- public spaces: the key for the social interaction
- green areas: a perennial goal
- working: downsizing and dispersion
- shopping: proximity and downscaling
- transportation: walking, bicycling, shared mobility and robo-taxies
- city scale: mixed use neighborhoods

9.1 Interior spaces: air quality

In the interior spaces, the virus transmission can be reduced by air control through ventilation, humidifying and filtering.

A 2020 research shows that 3 air changes per hour, which is common in most countries legislation, "generated reductions in expected outbreak sizes that would normally only be possible with a substantial vaccination coverage of 50–60%, which is within the range of observed vaccination rates in school settings [63]".

As for filtering, pre-pandemic experiments have been conducted since 1968 on the efficiency of HEPA filters that "showed an average reduction of 99.996% [66]" or in which "aerosol transmission of PRRSV occurred in 0 of the 10 HEPA-filtration replicates [67]". During COVID-19 pandemic, HEPA filters were recommended in hospitals for air filtering in operating rooms or in the breathing circuit [68, 69]. Some papers recommend HEPA for filtering the recirculating air in closed rooms or vehicles [70, 71], although certain studies are reserved concerning the HEPA filters capacity of filtering submicron size particles [70].

Humidifying could play an important role as long as a 2013 research concluded that "maintaining indoor relative humidity >40% will significantly reduce the infectivity of aerosolized virus [72]".

As in the 19th century, air control becomes a key measure in mitigating pandemics in 2020.

9.2 Residential: middle density and the intermediate housing

There seems to be a conflict between epidemiologic studies that suggest a lower people density and the environmental approach that recommends the increasing of the built density. The urban sprawl is considered to increase pollution, to cause the loss of a sense of community [73], global warming [74], higher transportation costs and create health effects due to the dependence on automobiles [75]. It is addressed by professional organizations such as Architects' Council of Europe, the American Institute of Architects and the American Planning Association, by agencies such as European Environment Agency or by national legislation, such as the French law for Solidarity and Urban Renewal.

On the other hand, lowering the people density is not only implied by studies carried over time that correlate population density and pandemics but also the public preference. Pre-pandemic surveys showed that 76% of French [76] and 80% of US Americans [77] would choose to live in single-family houses. The COVID-19 pandemic increased this desire. Teleworking and the reduced access to shops, "led to a reduced demand for housing in neighborhoods with high population density", trend which strengthen after the market recovery in June 2020 [78].

The solution to reconcile the dense city environmental paradigm with the low density of population suggested by epidemiologic studies can only find the answer in architecture and urbanism. For most epidemiological approaches, people density is a figure in a quantitative approach while for architecture and urbanism there is also a shape-related morphological and typological building approach. Urban approach also considers different densities, such as population density (related to inhabitants' number), residential density (related to number of housings) or built density (related to gross floor area). Moreover, the same people density can be achieved with different urban typologies, such as parallel buildings, courtyard or scattered. Architectural approach also takes into account building morphology. The same people density can be achieved under different morphologies, such as detached houses, row houses or blocks. Therefore, addressing population density as a figure is not enough for analyzing the complexity of the built environment.

A more detailed approach should also be based on studies carried over the virus transmission in the interior spaces. Small, confined and poorly ventilated spaces, such as stairs or elevators, must be carefully planned as they are the most susceptible for aerosol contamination [79].

Medium density environments are the mostly supposed to reach this goal. Both New Urbanism and Urban village movements promote medium density housing. There are urban and architectural approaches that stay in between the single family detached house and the block paradigm. The French Intermediate Housing concept addresses buildings with more than one superposed apartments and with private access to each apartments. The definition appears in a French 1973 decree: the social intermediate housing (*habitat social intermédiaire*) is supposed to have a private access, a private exterior space of one quarter of the apartment surface and a height of no more than three floors. The organization led to densities of 80 to 100 dwellings per hectare for intermediate housing compared to the 10–50 dwellings per hectare for dense single-family houses [80].

9.3 Public spaces: the key for the social interaction

One of the problems the COVID-19 pandemic created was the social disruption. The public space was put under scrutiny [81]. In this matter, exterior public spaces could play a key role. The COVID-19 droplets transmission occurs up to 6 feet (2 meters). According to Edward T. Hall's proxemics theories, the social distance far phase is in between 7 and 12 ft. (2.1–3.7 m) and the public distance is in between 12 and 25 ft. (3.7–7.6 m) for the close phase and more than 25 ft. (7.6 m) for the far phase. Therefore, far social and public contacts could be achieved in exterior spaces without transmission risks.

According to Jan Gehl's theories, social contacts in public spaces are among the most important. They have the characteristic of being spontaneous because people interact as a result of necessary or optional activities. The space in between the buildings is ideal for conversation, greetings, children playing: "life between buildings as dimension of architecture, urban design and city planning to be carefully treated [82]".

9.4 Green areas: a perennial goal

As recent scientific studies show, green areas can improve the response to pandemics. They were already present in the 1900s urban theories and they maintain their permanent importance.

9.5 Working: downsizing and dispersion

Architectural measures can be taken in the case of office buildings. Some approaches concern general building measures, such as air control by ventilation filtration and humidification. Other methods should lean on morphologic changes that consider access separation and office space distribution.

There is also question of the offices size and their urban distribution. During the COVID-19 pandemic, an Italian multicriterial research concluded that firm density, based on an over 250 employees firm index for each region, was positively associated with higher fatality rates [36].

The COVID-19 pandemic also accelerated the use of telecommuting (teleworking or working from home). In 2019, 5.5% of workers in the US already worked from home [83] and, in April 2020, already 20% of Americans were able to work from home and doing so [84]. Estimations from 2020 are that "37 percent of U.S. jobs that can plausibly be performed at home account for 46 percent of all wages [85]". Telecommuting has an indirect environment impact by reducing the greenhouse emissions, fuel and energy usage and network congestion [86, 87].

9.6 Shopping: proximity and downscaling

Apart air quality methods, different measures can be taken for shops. Reducing the size cold lead to a better ventilation and less potential contacts. Proximity shopping is also an environmental desideratum as it allows for less automobile transportation, lead to pedestrian cities, reduced pollution, less energy consumption and less environmental impacts. Recent study shows that "to achieve a balance between energy consumption, GHG [Greenhouse Gas] emissions and energy generation potential, a neighborhood should contain an optimal ratio of commercial to residential buildings of about 0.25 [88]."

The proximity and downscaling decision have long term social and environment motivations more than short term economic reasons. An example are hypermarkets, huge stores combing supermarkets to department stores. It is symptomatic how France, the country that first implemented hypermarkets with Carrefour, in 1963, prevented their implantation in cities ten years later, by the Royer law which regulated the creation of shops over 1500 m^2 inside towns.

9.7 Transportation: walking, bicycling, shared mobility and robo-taxis

Before the pandemic there was already very strong evidence of aerosol transmission over long distances [89]. Studies during 2020 showed substantial transmission in closed vehicles and suggest "future efforts at prevention and control must consider the potential for airborne spread of SARS-CoV-2, which is a highly transmissible pathogen in closed environments with air recirculation [90]". At the beginning of 2020, studies drew a warning about public transportation showing that, for New York City, the subway system was the major disseminator of COVID-19 [91].

To keep the present transportation system there could be applied methods that reduce the viral transmission. Airborne virus spread in public transport can be reduced by installing HEPA filters and surface disinfection can be done by UV disinfection.

There is also question of changing the current transportation paradigm. Changes that may reduce the virus transmission in the transportation system already begun before the COVID-19 pandemic. Cities designed at the scale of walking or bicycle distances were proposed by the 1900s Garden City movement, the 1970s Intermediate Housing or 1980s New Urbanism and Urban Village movements.

Mobility sharing with bicycles can increase the efficiency of an urban public transport network [92] and has health benefits [93]. Starting with the white bicycle and white path proposed by the Provo movement in Amsterdam, in 1965, the Vélib' in Paris, launched in 2007 and reached the Chinese bike sharing system where the two largest operators, Ofo, launched in 2014, and Mobilke 2015, totalize over 50 million orders per day [94]. Electric car sharing, on which UV disinfection could be applied, could be a pandemic and environmental solution too. It has a positive environmental approach by "reducing 29% of CO2 emissions and increasing 36% electric vehicle adoption, when compared to the business-as-usual scenario [95]". Along with UV disinfection, robo-taxis (robo-cabs, self-driving taxis or driverless taxis) could be used. Experiment in Beijing with electric robo-taxis showed a good impact in lower energy consumption, zero tailpipe emissions, traffic decongestion and reduced health risks [96] while simulation in Milan "propose that introducing a robo-taxi fleet of 9500 vehicles, centered around mid-size 6 seaters, can solve traffic congestion and emission problems in Milan [97]".

From the larger urban point of view, transportation is influenced not only by the means of transport but also by the overall cities' organization.

9.8 City scale: mixed use neighborhoods

Reducing transportation while maintaining social contacts and the access to urban facilities is a key aspect in preventing and mitigating pandemics. Research done during the 2020 pandemic suggest that "connectivity matters more than density in the spread of the COVID-19 pandemic [98]". The risks are represented by commuting, tourists and businesspeople. Studies emerged during pandemic concern health inequities derived from the urban development [99].

This desideratum can be reached by designing mixed use neighborhoods that could concentrate transportation on walking and bicycling. These neighborhoods are likely to lead to a medium density environments [100]. They should combine living with working, leisure, education and public space encounters.

The concept is not new, as it is already present in Ebenezer Howard's Garden City with self-contained mixed-use new towns and socially mixed population. It is also relevant for the US 1980s New Urbanism or for the European Urban Village.

10. Opportunities

There is a consistent scientific literature about the opportunities highlighted by COVID-19 pandemic in different domains. There is also an expressed confidence that "architecture and urbanism after the COVID-19 epidemic will never be the same [101]". Some built environment related trends may be accelerated by the pandemic:

- the recognition of the role of environmental impacts on zoonosis, such as deforestation and destroying natural habitats
- an increased awareness of the public space importance
- the architectural research on new medium density typologies
- the acceleration of promoting mixed-use neighborhood and encouraging walking and bicycle transportation
- accelerate advancements in transportation such as shared mobility and robo-taxis.

11. Conclusion

Healthcare shape our cities and vice versa.

Although fighting against pandemics was traditionally associated with the built environment, the 20th century pharmaceutical progress allowed medicine to emancipate from architecture and urbanism. As WHO stated in 2018, "Will history repeat itself? The answer must be: Yes, it will [1]." Last decades evolutions which culminated with the COVID-19 pandemic stretched the role of a new interdisciplinary strategy in both combating and mitigating future outbursts.

There is an important COVID-19 scientific literature concerning pollution, green areas role, urban population density or air control that can be addressed mainly through built environment measures. These measures include air control, residential measures, public spaces, green areas design, working, transportation and mixed neighborhoods.

The COVID-19 pandemic dramatic implications can be also perceived as an opportunity for setting up a more stable health and built environment systems. Scientific evidence is not enough and it should be doubled by public awareness and by political implication. Otherwise, it may end like *The Great Illusion*, the 1910 book of the Nobel Prize winner Sir Norman Angell, which, although scientifically proved that economic interconnection among nations made future wars illogical and counterproductive, was followed by two World Wars.

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