HEALTH ENGAGED ARCHITECTURE IN THE CONTEXT OF COVID-19

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ABSTRACT

In the context of the COVID-19, this article reveals the potential of architecture and urbanism in the prevention and control of epidemics and in playing an active role in human health. The historical approach shows that the same space-controlled measures against pandemics were used for centuries to combat leper or plague: quarantine, isolation and confinement. The fight against tuberculosis led, from the 1830s, to the hygiene movement which facilitated current principles for a healthy architecture regarding sunlight and ventilation. In the 1920s, hygienic concepts constituted the foundation for modernist architecture and urbanism. With the advent of antibiotics, in the 1940s, medicine was emancipated from architecture. In the 1970s, the criticism of the social modernist shortcoming led to the New Urbanism or Urban Village movements and environmental issues to Green Architecture and Urbanism.

The paper investigates how the present pandemic confirms the last decades warnings and the previous concerns about the correspondence between population density and mortality rates. The article examines the linkages between scale in the built environment, epidemiology and proxemics. The goal is to determine the place of architecture and urbanism in social resilience management during pandemics.

Solutions for health engaged architecture and urbanism are indicated at different scales: object scale—hygiene; people scale—distancing and isolation; interior spaces—air control by ventilation, filtering and humidifying; residential—intermediate housing, public spaces between buildings—the key for social interactions; working—telecommuting, size and dispersion; shopping—proximity and downscaling; transportation—walking, bicycling, shared mobility and robo-taxies; and higher scale-mixed use neighborhoods.

Architectural certifications such as BREAM and LEED may need to implement similar guidelines for public health. Healthy building movements like Fitwel and WELL Building Standard have already taken steps to foster healthy urbanism, and LEED for Neighborhood Development addresses health related issues. In the context of the COVID-19 and the concern of future pandemics, research in these areas will need to be expanded.

KEYWORDS

COVID-19, SARS-CoV-2, coronavirus, epidemics, pandemics, architecture, urbanism, health, ecology

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INTRODUCTION

In the context of the COVID-19, this article reveals the potential of architecture and urbanism in the prevention and control of epidemics and in playing an active role in human health. The paper compares historical pandemic approaches to the present pandemic situation, then goes through epidemiologic studies to identify architectural and urban solutions and finally summarizes the guidelines for a health engaged architecture.

HISTORICAL METHODS AGAINST EPIDEMICS BY MOVEMENT-CONTROLLED MEASURES

In the absence of adequate medical treatment, movement-controlled measures were the first historical methods against contagious diseases. These measures are part of the epidemics containment, not treatment: **isolation** (the separation of ill or infected persons from others to prevent the spread of infection or contamination), **quarantine** (which involves the restriction of movement of healthy persons who may have been exposed to the infectious agent) [1] and **confinement** (for healthy or asymptomatic persons).

For the leper, in the Middle Ages sick people were isolated in leprosy asylums. They suffered also from social exclusion by the obligation of wearing special clothes and a bell or a clapper to warn of their approach.

Measures against plagues were even more diversified as the disease had a greater mortality. Several plagues affected Europe, the most notable being the 1347–1352 Black Death which killed between 25 to 50% of Europe's population. There was a lack of medical treatment; the movement-controlled measures during plagues were isolation, quarantine, confinement and medical passport. The term quarantine itself originates from the Italian *quarantena*, meaning the forty days imposed in 1448 by the Venetian Senate to overcome the 37 days bubonic plague incubation period. Confinement was used in London in the 18th century and confinement measures led to the 27 km Plague Wall in the French Vaucluse mountains. It was only in 1896 that Alexandre Yersin discovered an anti-plague serum.

Tuberculosis, the so-called "white plague," is another consequential disease for humanity. Even in 1900, tuberculosis remained the third cause of death after cardiovascular diseases and influenza–pneumonia [2]. Although Robert Koch identified the tuberculosis bacillus in 1882, there was still no valid treatment for more than half of the century.

The 1918 Spanish flu was a pandemic most similar to the current COVID-19 crisis and gives us a clearer image of the impact of movement-controlled measures, such as social distancing. The epidemics lasted two years and epidemiologists "estimate the death toll as probably 50 million and possibly as high as 100 million," [3]. An American study on cities that implemented NPIs [non-pharmaceutical interventions], such as social distancing, proved that "cities that intervened earlier and more aggressively do not perform worse and, if anything, grow faster after the pandemic is over. Our findings thus indicate that NPIs [non-pharmaceutical interventions] not only lower mortality; they may also mitigate the adverse economic consequences of a pandemic. [4]"

At least six flu pandemics have been identified in Europe: a pandemic in the 16th century, the 1918 H_1N_1 Spanish flu, the 1957 H_2N_2 Asian flu, which killed an estimated 1 to 4 million people, the 1968 H_3N_2 Hong Kong flu, which killed an estimated 1 to 2 million people globally, the 1997(2003) H_5N_1 avian influenza and the 2009 H1N1/09 swine flu. Contemporary public health researchers have anticipated a new 7th pandemic, so in certain respects, the current Covid-19 crisis is not a surprise [5].

FIGURE 1. The Black Death spread rapidly along the major European sea and land trade routes in medieval Europe. The colors indicate the spatial distribution of plague outbreaks over time: the spread of plague in the 1340s, 1347, mid-1348, early-1349, and late-1349. Areas that escaped with minor plague outbreak are in green. (Source: Wikimedia Commons)

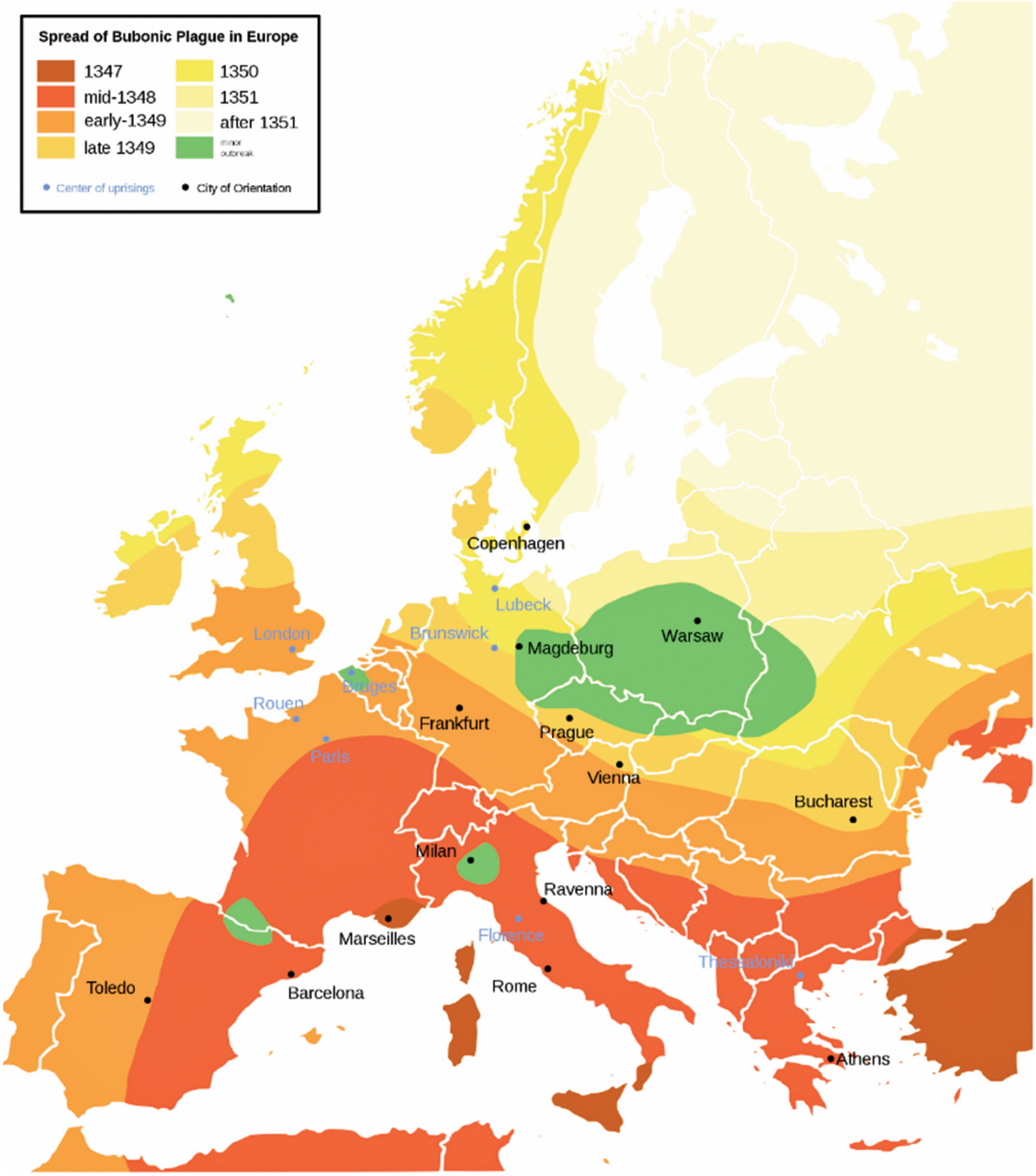


FIGURE 2. A quarantine ship out near Sheerness (Standgate Creek)—one of the earliest and longest-used forms of defense against sea-borne disease. UK National Maritime Museum, author unknown. 19th century. UK National Maritime Museum. (Source: Wikimedia Commons)

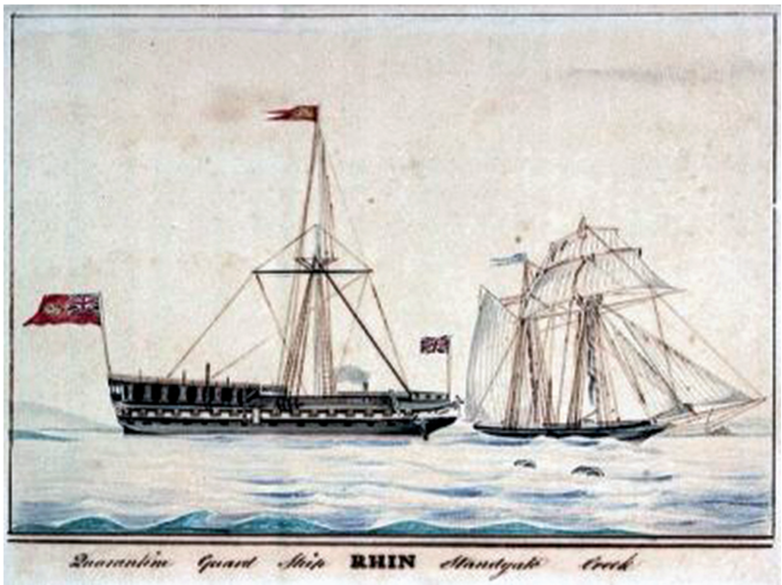
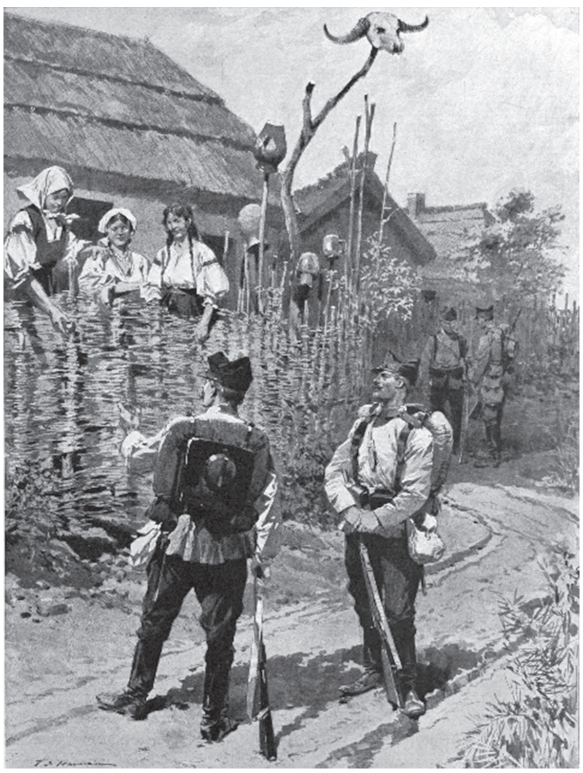


FIGURE 3. Frédéric De Haenen (1853–1928) based on sketches by Rook Carnegie (1860–1908). Print of villagers isolated in Romania because doctors suspected cholera on 18 November 1911, The Illustrated London News, p. 821. (Source: Wikimedia Commons)



ARCHITECTURE AND URBANISM FOR PREVENTION AND CONTROL OF EPIDEMICS IN THE LAST TWO CENTURIES

The 19th century tuberculosis solution was the alliance between architecture, urbanism and medicine that led to a new town morphology. The hygiene movement in France was a mix of architecture and urbanism with medical approaches aimed for the public health [6]. The movement started in Paris in the 1820s, led, in 1948, to the creation of the Hygiene Commissions and, in 1950, to the Commission for Unhealthy Housing [7]. Its application of principles reached a climax in the Seine (Paris) prefects Rambuteau (1833–1848) and especially Haussmann (1853–1870). The theories were used at an urban scale unknown before and became an international model: water drains, wastewater treatment, waste removal, air circulation, lighting and sunlight were targeted solutions. Tuberculosis sanatoriums, where sunlight reached living areas in order to kill the bacillus and other germs, became the scientific architectural model. The architectural prescription which states that the maximum building height will not exceed the street width is a hygienist tuberculosis result. Contemporary urban approaches tend to forget that urbanism was born from the medical and building professions attempting to alleviate public health and sanitary crises. Later, in 1908, France enacted *the Law for the Public Health Protection*.

Nearly at the same time, the counterreaction to the "crowded, unhealthy cities [8]" lead in England to the Garden City movement, which started with Ebenezer Howard's 1898 book, *To-morrow: A Peaceful Path to Real Reform*, republished in 1902 as *Garden Cities of To-morrow*. Although the "garden" component of the approach may be the most visible, Howard addressed city problems with a complex and still very contemporary approach by conceiving of a network

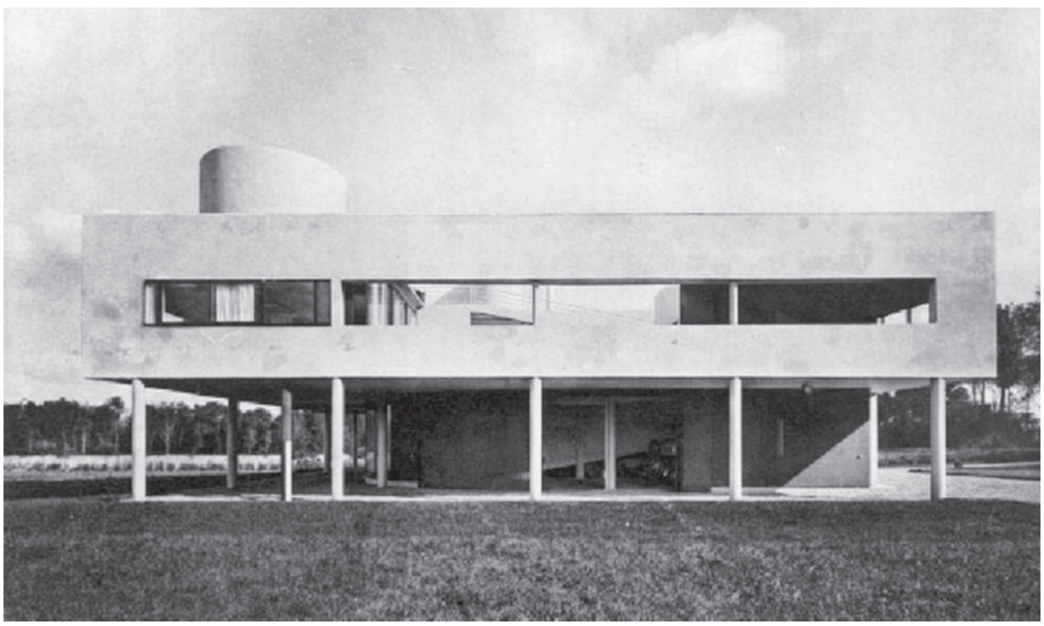
FIGURE 4. Galais, F. (1918) Dessinateur, Un Grand Fléau. LA TUBERCULOSE. (Source: Bibliothèque nationale de France.)

of new towns with socially mixed populations, self-containment and mixed-use. In Germany and Switzerland the back-to-nature *Lebensreform* (Life Reform) movement emerged which also had town planning results [9].

In 1904 Paris the First International Congress for Sanitation and Housing Health Safety was held. The first section was dedicated to Urban Housing and **links population density to public health**: "In urban agglomerations where space is not closely measured, where population can spread on surfaces constantly enlarged, it is possible to build houses, to create public roads responding to all the wishes of hygiene, to broadly provide air and light, to reduce the height of homes, to avoid people overcrowding, in short to more or less realize the existence conditions called by M. E.[Émile] Trélat [former architect in chief of the Seine Department/Paris] dispersed life. [10]" The report quotes the 1904 Paris Sanitary Regulations which control construction, living areas, undergrounds, air circulation, illumination and sunlight, openings, courts, gardens, kitchens, heating, and ventilation. Relevant are the French tuberculosis statistics depending on the total number of building floors and individually for each floor. Professor Manolescu, wrote about Romanian standard architectural projects [11]. The French Dr. Samuel Bernheim makes note of the European study on the influence of houses in the spreading of tuberculosis which states 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.** [12]"

As medical treatment was still not available, in the Interwar period the hygienists approach put its mark on modernist architecture. Le Corbusier's *Five Points of a New Architecture* are

FIGURE 5. Le Corbusier, Villa Savoye, Poissy, France, incorporates the architect's Five points: the house on *pilotis*, reinforced concrete columns that raise the house from the ground, the roof garden, the free plan, the horizontal window and the free façade. (Source: CAMPBELL, MARGARET (2011): Le Corbusier, Villa Savoye, Poissy, 1928, FLC L2 (17) 4. Figure. https://doi.org/10.6084/m9.figshare.23682.v1)



largely inspired by anti-tuberculosis hygienist theories: the house on *pilotis*, reinforced concrete columns that raise the house from the ground that free it from the "dark and often humid premises," the roof garden, for "technical, economy and comfort reasons," the free plan that uses the reinforced-concrete to liberate it from being the "slave of the load-bearing walls," the horizontal window, is an "essential goal of the house," which "runs from one end to the other of the façade" and the free façade in front of the columns, "lightweight membranes made of isolating walls or windows." Le Corbusier's theoretical work starting with the 1924 *Urbanisme* book and different projects, such as the *1922 immeuble-villa* for Marseilles, marked the Modernist movement.

Modernist hygienist inspired architectural approaches continue with the 1925 Jan Duiker's Zonnestraal sanatorium, the 1927 Weissenhof Seidlung (White Housing) exhibition in Stuttgart, the 1929 Alvar Aalto's Paimio tuberculosis sanatorium, the Modern Architectural Research Group (MARS) or E. Maxwell Fry in England [13].

Modernist urbanism based on health knowledge took a further development with the 1933 Le Corbusier architect *Athens Charter* and the 1942 Josep Lluís Sert's *Can our cities survive?*. Dwellings were supposed to have light, sun and ventilation and buildings were supposed to be sun oriented. In 1943 the discovery of streptomycin by Selman Waksman, among other antibiotics, brought about viable treatments for tuberculosis. **With the advent of antibiotics, medicine emancipated from architecture.**

HYGIENIC ARCHITECTURE AND URBANISM DRAWBACKS

Social environment impact

Social disfunctions are among the biggest threats of hygienic-derived urbanism. Modernist urbanism principles of the 1930s, derived from health concerns which emphasized sun, light and air issues, promoted functional segregation, automobile-based traffic and led to the disappearance of streets in favor of multistory buildings surrounded by large parks. It was only in the 1970s that residential cities could be evaluated. Social conditions degraded due to the greater distance between people, automobile-based transportation, functional separation and the disappearance of the traditional streets and places for encounters. In more recent decades suburban sprawl with single-family housing also lead to the automobile-based transportation, social segregation and to minimum social interaction on the streets, leaving the shopping centers as main encounter spaces.

Urban counterreactions

The US 1980s **New Urbanism** is a movement that reacted to the urban social environment decline by promoting mixed-use neighborhoods instead of the functional segregation of residential from commercial and industrial development and to the automobile-based transportation by encouraging walking and bicycle transportation [14]. The concept is not new, as Ebenezer's Howard Garden City presented the idea of a self-contained mixed-use new towns with socially mixed population. The New Urbanism promotes a human scale urban design.

The **Urban Village** is a contemporary European movement which is also promoting medium-density housing, mixed use zoning aiming for partial self-containment by combining working, leisure and living and encouraging walking and public space encounters. One example may be the French Plessis-Robinson, named in 2008 "the best urban neighborhood built in the last 25 years" by the European Architecture Foundation.

Although it does not directly address health issues, these movements may give answers to some of the hygienic urbanism drawbacks. Assessing the impact of the COVID-19 measures is important because they present the same social and biophysical environment threats as the previous hygienic derived movements, such as the decline of public transportation and the decrease in number of social interactions.

Biophysical environmental impact

Modernist urbanism of the 1930s, derived from hygienic principles led to automobile-based traffic. This phenomenon accentuated pollution and carbon emission. Pollution and sedentarism caused by automobile transportation led to adverse health effects such as obesity or hypertension. The single-family housing suburban sprawl of the last decades led to the same automobile-based traffic environmental problems. It also led to agricultural land loss, water pollution, increase in resources and energy use, infrastructure expenses, and risks in natural hazards.

Urban counterreactions

Green architecture started in the late 1960s as a response to suburban sprawl and to the energy crisis. The urban approaches range from green city, sustainable city, eco city, zero & low carbon cities, zero energy city, livable city, compact city, smart city or resilient city. Current environmental urbanism addresses pollution and carbon emission, energy and water consumption, water quality, energy mix, waste volumes and recycling rates, green-space ratios, primary forests, and agricultural land loss.

THE RECENT WARNINGS ABOUT POSSIBLE ZOONOTIC PANDEMICS

Zoonotic infections, i.e. caused by a pathogen that jumped from animals to humans, are not new. "Of the 1,407 human pathogen species, 816 (58%) are known to be zoonotic. [15]" What changed dramatically over the last decades is the increase in number [16] of those diseases affected by the intensive agricultural intrusion in ecosystems [17, 18] or climate change [19]. There is also a question of a **new animal health safety paradigm** [20]. Among the most known zoonotic diseases we may cite HIV/AIDS or the last zoonotic epidemics such as avian influenza (bird flu), bovine spongiform encephalopathy (mad cow disease), Ebola, Middle East respiratory syndrome (MERS), sudden acute respiratory syndrome (SARS), West Nile virus, Zika virus disease and the new COVID-19 coronavirus.

During the last decades epidemiologists launched warnings that described precisely the present COVID-19 pandemic health, social and economic impact:

"**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.** [21]"

The importance of this concern was such that the 2016 United Nations Environment Programme report about the "Emerging Issues of Environmental Concern" puts zoonosis in second place out of the six topics, right after the Financial Sector. It states that "**there is a worldwide increase in disease emergence and epidemics particularly from zoonosis**—diseases that can be passed on between animals and humans. The report illustrates how the emergence and re-emergence of zoonotic diseases are closely interlinked with the health of ecosystems. The risk of disease emergence and amplification increases with the intensification of human activities surrounding and encroaching into natural habitats, enabling pathogens in wildlife reservoirs to spill over to livestock and humans. [22]" It also connects this concern to the first issue "**that the global significance of the financial sector should not confine itself only to enhancing global economic growth, but also to advancing environmental sustainability** [23]."

VIRUS TRANSMISSION AND URBAN DENSITY

Certain late 20th century reports already link the high-density city to the pandemics. **The 2020 April COVID-19 death rate map in the EU, Italy (Figures 6–8) or in the US matches almost perfectly the population density map.** On the contrary, it does not superpose with other maps, such as Educational attainment, Per capita income or Median value of specified owner-occupied housing units.

From the epidemiologic point of view, population density is not a new topic as, in the last decades, scientific studies investigated epidemics of tuberculosis or avian flu in connection with population density [24–27] or how urban form and land use can influence transmission of a vector-borne virus [28]. From the urban point of view, most researches on urban density switched from people health to environmental health. These studies concentrated on the relationships between energy and form, morphology and density in urban environments [29–32].

Judging by the mortality rate and density statistics, **some may conclude that a measure against the spread of pandemics would be simply be to lower urban density**. This approach would be contrary recent recommendations to reduce urban sprawl and, therefore, to increase

FIGURE 6. Italian population density (per province). Source: Wikipedia.

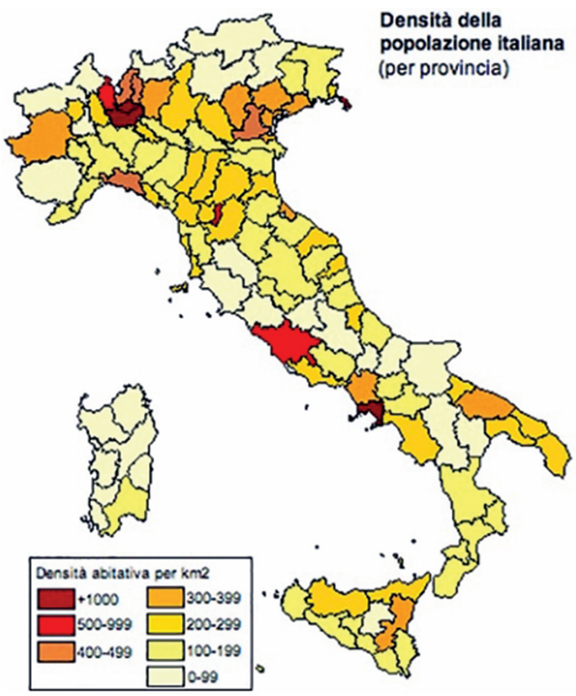


FIGURE 7. Map of provinces with confirmed coronavirus cases. Source: Wikimedia Commons

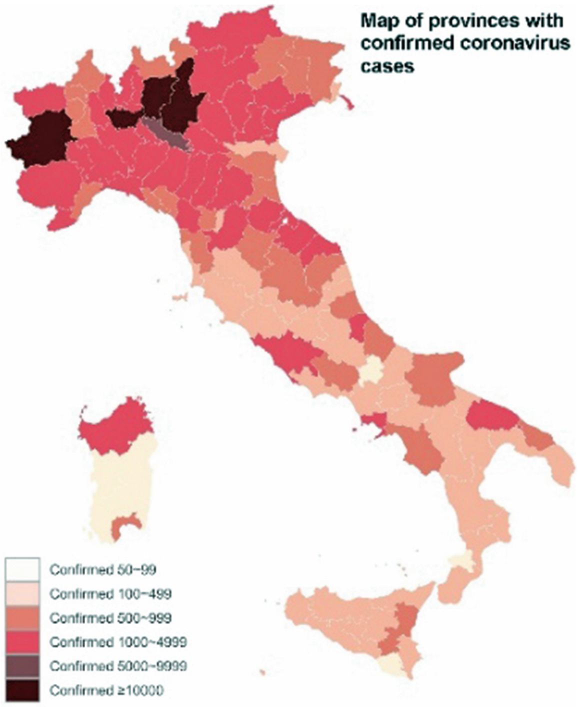


FIGURE 8. Cumulative incidence per 100.000 inhabitants. Source: Sorveglianza integrate nazionale.

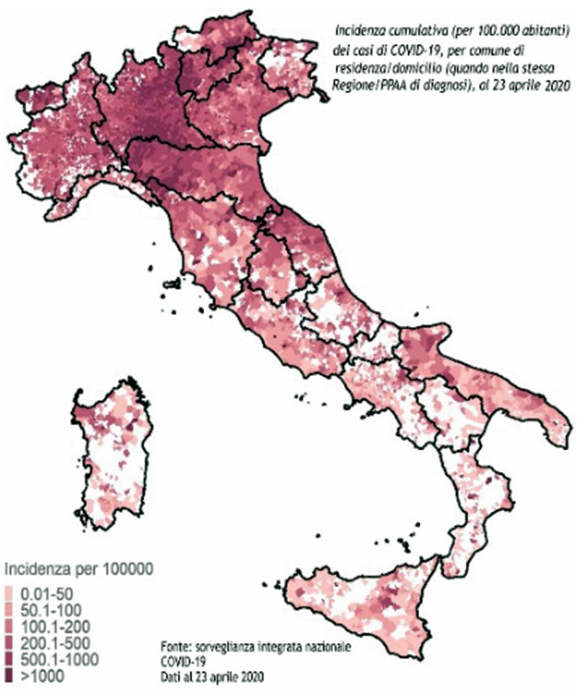
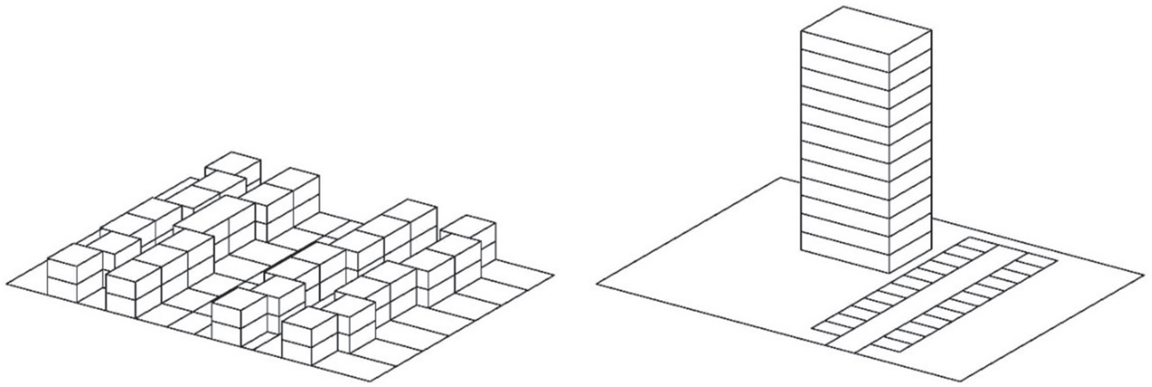


FIGURE 9. The same urban built density with different morphologies. (Source: the author)



density. Professional associations consider that urban sprawl not only creates environmental problems, affect safety, increase transportation costs and have negative social outcomes, but also have negative health effects caused by the increase in air pollution or by the dependence on automobiles, such as obesity or hypertension. Working against urban sprawl are professional associations, such as the American Institute of Architects and the American Planning Association, European Environment Agency, or countries legislation, such as the French law for Solidarity and Urban Renewal. The position against urban sprawl position is not shared by the public. A 2007 survey showed that 76% of French would choose to live in single-family houses outside towns (56% isolated detached houses, 20% in suburban housing complexes) and 11% in small individual houses in towns, the rest of 13% preferring condominiums or apartments, while only 49% of respondents actually lived in single-family houses outside towns [33]. A 2011 US survey showed that 80% of Americans "would prefer to live in single-family, detached houses over other types of housing such as townhouses, condominiums, or apartments [34]."

Lowering population density in order to reduce a viral pandemic spread may be too simplistic of an architectural approach. Firstly, different urban densities are being measured: population density (inhabitants' number/surface in square kilometers or hectare), residential density (number of housings/surface hectares) or built density (gross floor area/plot area). Several indicators are used in European urban sprawl analysis, such as PBA (Percentage of built-up area), LUP (Land uptake per person, that is per inhabitant or job) or UPU (Urban permeation units) [35]. Secondly, although we tend to link the people density to the urban morphology, such as detached houses, row houses or blocks, or to urban typology, such as parallel, courtyard or scattered, we may obtain the same density for different morphologies, such as small height housing or big height blocks (Figure 9).

The architectural point of view may be that, although COVID-19 mortality rate and incidence seem linked to the population density, there is no proof that the density itself is the cause for the virus spread. The question of analysis scale must be addressed.

THE SCALES IN THE BUILT ENVIRONMENT, EPIDEMIOLOGY AND PROXEMICS

During pandemics, resilience should absorb disturbances not only in health and economy but also in the social environment. This article approaches the correspondence between the scales in the built environment, epidemiology and proxemics. The goal is to determine the place of architecture and urbanism in social resilience management during pandemics.

The COVID-19 virus can transmit at three building scales:

At the smallest level, **the object scale, the contamination occurs by surface-to-person transmission (fomite), i.e. when somebody touches a contaminated surface and then touches his/her mouth, nose, or eyes. At this scale, people may protect themselves by good hygiene.**

At **the architectural scale, the contamination occurs not only by person-to-person transmission, i.e. by inhalation of liquid droplets within about 6 feet (2 meters)** [36]**, but also by aerosol transmission**. In contrast to the liquid droplets, aerosols are suspensions in air of finer particles that can remain airborne for hours. **Protection is more difficult and, unless more complex measures are taken, one can protect himself only by wearing protective equipment such as filtering masks and eyeglasses.**

At the highest level, the **urban scale, people may protect themselves from person-to-person droplets transmission by distancing**.

The scales are important from the social point of view. According to the cultural anthropologist Edward T. Hall, the founder of proxemics, there are four distance zones compiled from observation of adult US northeastern seaboard natives: the intimate distance, with a close phase (less than 6"/15 cm) and a far phase (6–18"/15–45 cm), the personal distance, with a close phase (1½–2½ ft/45–75 cm) and a far phase (2½ ft–4 ft./0.75–1.2 m), the social distance, with a close phase (4–7 ft./1.2–2.1 m) and far phase (7–12 ft./2.1–3.7 m), and the public distance, with a close phase (12–25 ft./3.7–7.6 m) and a far phase (more than 25 ft./7.6 m). The COVID-19 droplets transmission occurs up to 6 feet (2 meters) which is in the intimate, personal and social distance—close phase.

To summarize, the correspondence between the three scales in architecture, urbanism and proxemics is:

	Built environment	Epidemiology	Proxemics
Smallest scale	object scale	surface-to-person transmission (fomite)	intimate distance and personal distance
Intermediate scale	architectural scale	person-to-person droplets transmission and aerosol transmission	the social distance—close phase
Biggest scale	urban scale	no transmission outside buildings	the social distance—far phase and the public distance

The built environment scale of urbanism corresponds to the epidemiology scale of no transmission outside the buildings and to the proxemics scale of social distance in the far phase. **The urban public space is the less contaminated scale and also happens to be the richest in spontaneous social interactions.**

HEALTH ENGAGED ARCHITECTURE AND URBANISM OBJECTIVES

Contemporary medical methods imply not only treatment, information and education but also by implication, self-care, self-management and active engagement in peoples' health [37, 38]. While the US health expenditure grew from 5% of the GDP in 1960 to 17.8% in 2019 [39], it is pointed out that "patients are the most under-utilized resource, and they have the most at stake. [40]"

In turn, architecture and urbanism should not settle for a passive attitude by creating environments that are limited to not affecting health but should adopt an active attitude. An engaged architecture and urbanism should pursue the following objectives:

- **prevent and reduce the impact of future pandemics** and **help resilience management**
- **maintain physical health** by reducing obesity and cardiovascular diseases, through promoting utilitarian and recreational physical activities, such as walking and biking
- **preserve mental health** by preventing isolation and stress outcomes
- **support social cohesion** by creating public spaces between buildings
- **address environmental concerns**, as humans are at the center of concern for sustainable development.

HEALTH ENGAGED ARCHITECTURE AND URBANISM SOLUTIONS

At a first glance it may look as though the present solutions to the COVID-19 pandemic are contrary to the architecture and urbanism principles promoted only one year before the crisis:

- instead of creating spaces for public encounters, people are now concerned with confinement.
- the high-density city paradigm, with smaller footprint and more economic transports, is now under question because of the higher mortality rates in the highly inhabited areas.
- in place of privileging public transports, now private transportation is favored to prevent the disease spread

A more attentive look shows that some of the solutions have already been proposed and the present pandemic may only accelerate their development.

To deal with health issues or to achieve ecological goals, architecture and urbanism are not simply the application of technical innovations but the continuous research of new connections between spaces and of different relationships between buildings and public spaces. The following solutions encompass a large range of approaches that architecture and urbanism should integrate, from the object scale up to the urban scale, in the short term and over the long term:

- **object scale: hygiene**
- **people scale: distancing and isolating**
- **interior spaces: air control by ventilation, filtering and humidifying**
- **residential: intermediate housing**
- **public spaces between buildings: the key for social interactions**
- **working: telecommuting, size and dispersion**
- **shopping: proximity and downscaling**
- **transportation: walking, bicycling, shared mobility and robo-taxies**
- **higher scale: mixed use neighborhoods.**

Object scale: hygiene

The surface-to-person (fomite) transmission of COVID-19 is well documented. From the buildings point of view, the approach is display handwashing signage and regular cleaning for the common areas. Research still has to be done on material properties. A 2020 study showed that copper is among the most antiviral materials since the COVID-19 virus remains viable for only 4 hours compared to 24 hours on cardboard [41].

Sterilization with ultraviolet (UV) Light is now being considered to eliminate the virus on objects, although it cannot be used on skin [42]. Robot-controlled noncontact UV surface disinfection is already in use [43]. Public transportation COVID-19 disinfection with UV was launched in April 2020 in Shanghai buses, and, according to the company, is killing 99.9 % of viruses in 5 to 7 minutes [44]. In May 2020, the New York Metropolitan Transportation Authority started to use UV disinfection in subways and buses [45]. However, UV disinfection cannot be used while people are in the range of the rays.

People scale: distancing and isolating

The immediate measures to be taken during the pandemics, as virus transmission by inhalation of liquid droplets is limited to about 6 feet (2 meters), is keeping this safe distance. Sitting places have already been marked at safe distance in restaurants, waiting rooms or even in exterior places. To help reduce the liquid droplets spread, isolation solutions were contrived, such as acrylic or plexiglass isolating booth and cubicle partitions installed in offices open spaces or in restaurants. The Art Center Mediamatic in Amsterdam installed a new type of transparent enclosures called Serres Séparées, in order to practice social distancing measures [46].

Over the long term, isolation and confinement are associated with pathologies such as hypersensitivity to external stimuli, hallucinations, anxiety, panic attacks, memory deficiencies, concentration issues, paranoia and impulse control [47]. Therefore, further design is will have to work toward a compromise between distancing and isolating by creating social encounters as shown below.

Interior spaces: air control by ventilation, filtering and humidifying

At **the architectural scale, viruses can transmit in confined spaces not only by droplets transmission but also by aerosol** that can remain airborne for hours. Scientific studies still must be completed as "virtually all infectious disease dynamics models on influenza have thus far ignored aerosol-transmission [48]." An experimental study on COVID-19 "found that viable virus could be detected in aerosols up to 3 hours post aerosolization [49]" although the World Health Organization (WHO) is reserved about this study because the aerosols were generated by a high-powered machine that does not reflect normal human coughing [50].

A 2020 study on Wuhan hospitals concluded that the biggest concentration of SARS-CoV-2 was found in the toilets, not in the patient rooms or the patient hall [51]. Of particular concern for office buildings, according to recent research, open spaces were the main contagious ones, showing that COVID-19 "can be exceptionally contagious in crowded office settings such as a call center […] despite the considerable interaction between workers on different floors […] which indicates that the duration of interaction (or contact) was likely the main facilitator for further spreading [52]."

In interior spaces, virus spread can be reduced via air change, humidity and filtering. The role of air change is emphasized by a 2020 study that assessed the potential effects of bringing ventilation to 3 air changes per hour, the recommended level by the American Society of

Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), which "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 [53]" The conclusion of a Wuhan hospital study seems to return to the hygienist methods of two century ago: "room ventilation, open space, proper use and the disinfection of toilets can effectively limit aerosol transmission of SARS-CoV-2 [54]." Ventilation may also have the reverse role. The air conditioning system on public buildings may also increase the transmission of the COVID-19 virus. A study published on 2 April 2020, conducted in an air-conditioned, closed-window restaurant in Guangzhou, concluded that "droplet transmission was prompted by air-conditioned ventilation" and "strong airflow from the air conditioner could have propagated droplets from table C to table A, then to table B, and then back to table C [55]." Although it seems clear that the direct airflow could spread virus droplets from the table A to B, which is from the air conditioning towards the "exhaust fan," it doesn't explain how virus was spread to table C, unless virus travelled back from the return grille, through the duct and through the indoor unit and was blown back in the room through the diffuser. The study explicitly indicates that "the smear samples from the air conditioner were all nucleotide

FIGURE 10. Floor plan of the 11th floor of building X, site of a coronavirus disease outbreak, Seoul, South Korea, 2020. Blue coloring indicates the seating places of persons with confirmed cases. Source: Park SY, Kim YM, Yi S, Lee S, Na BJ, Kim CB, et al. (2020).

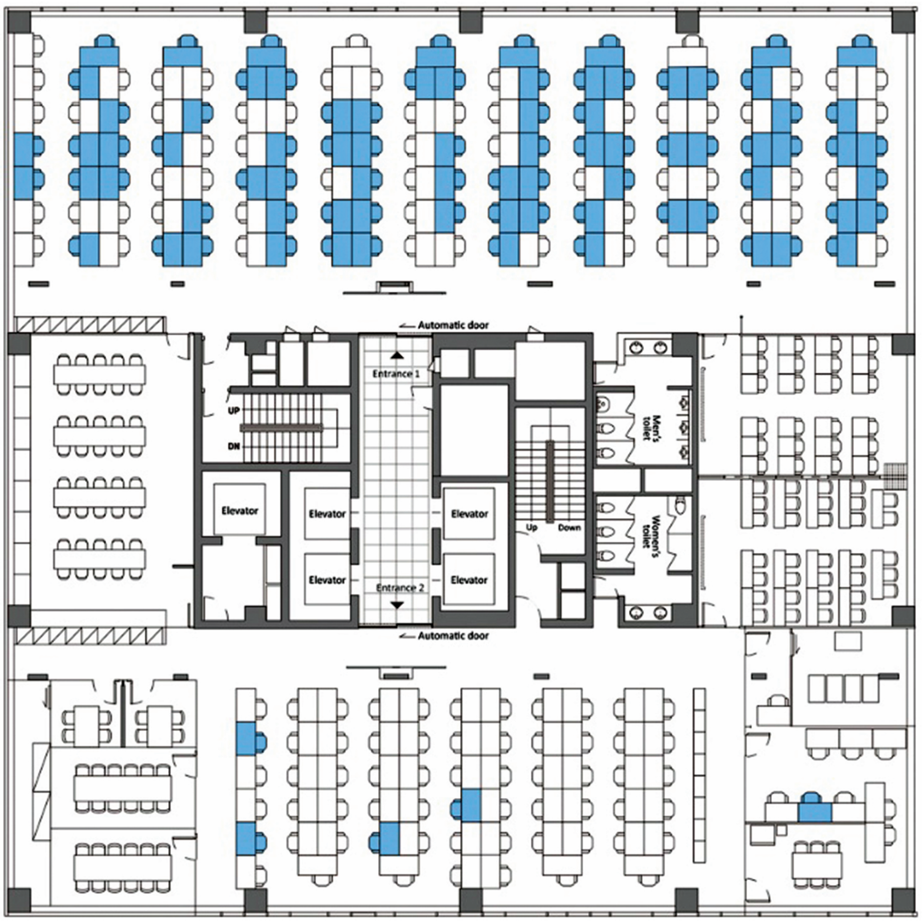
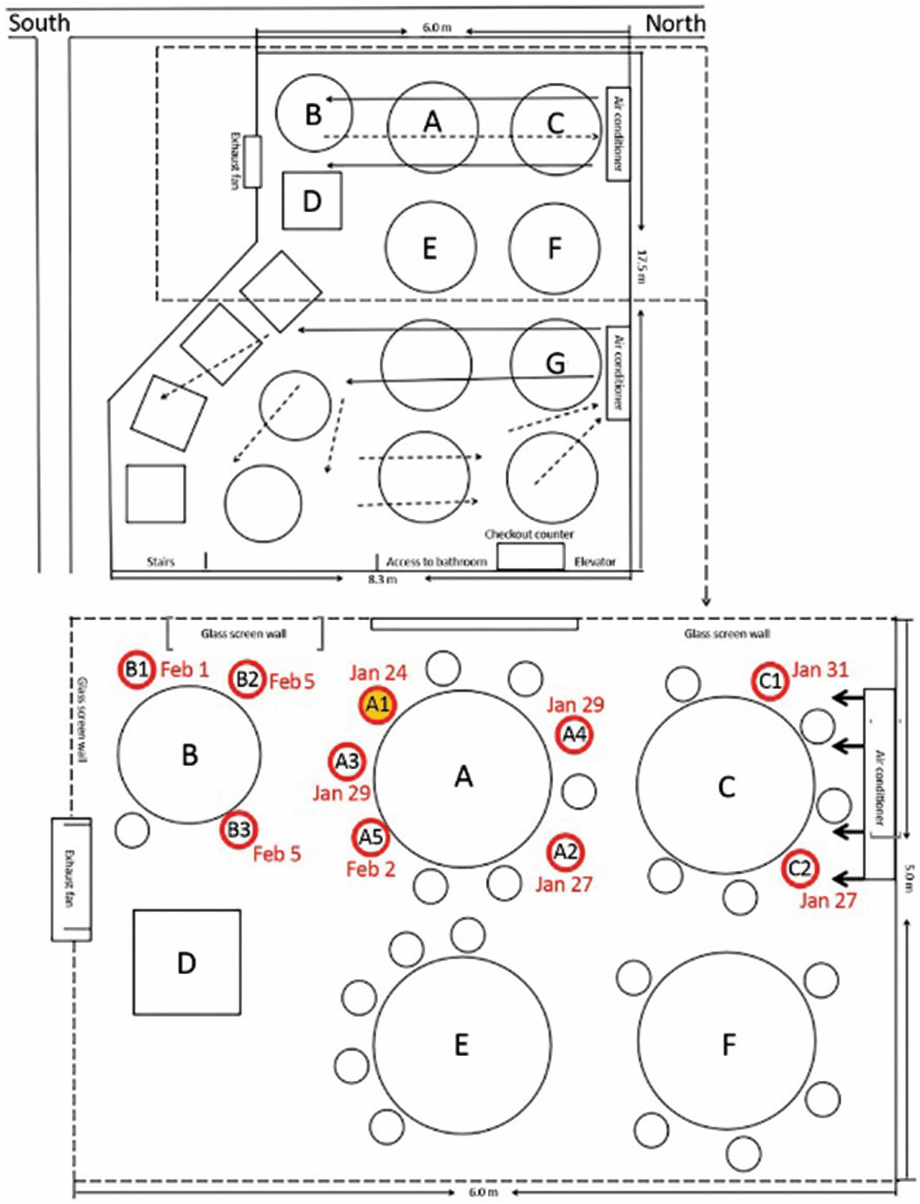


FIGURE 11. Sketch showing arrangement of restaurant tables and air conditioning airflow at site of outbreak of 2019 coronavirus disease, Guangzhou, China, 2020. Source: Lu J et al. (2020).



negative" but also adds that "this finding is less consistent with aerosol transmission." Therefore, the virus might have travelled through the central HVAC system.

On 14 April 2020, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHARE) issued a report confirming that "infectious aerosols can be disseminated through buildings by pathways that include air distribution systems and interzone airflows. [56]" ASHARE HVAC strategies are complex, ranging from directional airflow to central system filtration and relative humidity control. Moreover, ASHARE also indicates that "naturally ventilated buildings can go beyond random opening of windows and be engineered intentionally to achieve ventilation strategies and thereby reduce risk from infectious aerosols."

Air humidity can also play a role in the virus spread. A 2013 research showed that "maintaining indoor relative humidity >40% will significantly reduce the infectivity of aerosolized virus [57]."

Several researchers show the possibility of filtrating virus at a personal scale, with masks and breathing circuits, and at the architectural scale, applied to entire rooms. Since 1968, an experiment found that high-efficiency particulate air (HEPA) filters showed an average reduction of 99.996% [58]." A 2006 research on porcine reproductive and respiratory syndrome virus (PRRSV) transmission by aerosol concluded that "aerosol transmission of PRRSV occurred in 0 of the 10 HEPA-filtration replicates [59]." A study on heating, ventilation, and air conditioning (HVAC) filtration concluded that "recirculating HVAC filtration was predicted to achieve risk reductions at lower costs of operation than equivalent levels of outdoor air ventilation [60]." In the case of patients suspected or confirmed to have COVID-19., HEPA filters are recommended for air filtering in some hospitals operating rooms or in the breathing circuit [61]. Certain researchers express concerns about the HEPA filtering capacity under certain situations. According to a 2009 study, "HEPA filters may not provide adequate protection for all threats: viruses are submicron in size and have small median infectious doses [62]."

Concerning the air filtration of entire rooms, some papers "speculate" about the "possibility of reducing the contamination of a room or space, by cycling air through a HEPA or ULPA filter" deployed in different scenarios: rooms with infected patients or closed vehicles [63]. Other articles affirm that it is "reasonable to assume that placing a portable HEPA filtration system with a high frequency of air changes rapidly reduces the viral load within rooms without increasing the risk of disseminating the virus [64]. Some hospitals already used this system for COVID-19 patients, as Singapore General Hospital, which "had its own ventilation system with an integrated high-efficiency particulate air (HEPA) filter [65]."

Using HEPA filters for recirculating air may be a viable approach to reduce the risk of virus transmission in spaces of various sizes.

In summary, air ventilation is one of the keys for a health engaged architecture. It implies the need for more profound research and a balance between issues concerning health, economy and environment.

Residential: intermediate housing

In order to avoid virus contamination in common interior spaces, such as lobbies, stairs or elevators, the obvious solution are houses that have a separate access, i.e. the single-family house, but this approach encourages the urban sprawl with secondary, negative effects on environment and health. The common solution to reduce urban sprawl is to increase the urban density with apartments that superpose and have a common access, the apartment buildings, but these common spaces would be the contamination points.

There is a third way, **Intermediate Housing, which would be a building with at least one superposed apartment and with private access to each apartment**. The existence of this intermediate housing has a long history, but the French definition may be found in a 1973 decree: the social intermediate housing (*habitat social intermédiaire*) should have a private access, a private exterior space of one quarter of the apartment surface and with a height of no more than three floors. As Edward T. Hall, the founder of proxemics wrote, "happily, some architects are beginning to think in terms of two-, three-, and four-story developments designed with a view to human safety. [66]" Since then, the concept evolved into more complex shapes. According to the Strasbourg Urbanism Development Agency (ADEUS), intermediate housing is defined by the space organization that may be individualized by inhabitants by the presence of gardens or a private entry, by the density in between 80 to 100 dwellings per hectare and by an urban shape with no more than two stories plus attic, green spaces and proximity services. A French 2010 study reviewed several cases of 80 to 100 dwellings per hectare for intermediate housing compared to the 10–50 dwellings per hectare for dense single-family houses [67]. The architectural conception enriches the views and perspectives, diversifies typologies, creates intermediate spaces that privileged social contacts and contact with nature. **Intermediate housing could be a response to the pandemics as they address both separation and density issues.**

The public spaces between buildings: the key for social interactions

In the short term, social distancing generated dedicated projects. The architectural studio Precht designed a still unbuilt "Parc de la distance" in Vienna based on the rules of social distancing. The vegetation is designed as a framework to keep visitors 240 cm from each other [68].

In the long term, measures must be taken to support social resilience, "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks [69]." During pandemics, the resilience capacity concerns "both the disruption caused by the restricted travel and social distancing, and the incidence of the disease. We find that while intervention strategies, such as restricting travel and encouraging self-initiated social distancing, may reduce the risk to individuals of contracting the disease, they also progressively degrade population mobility and reduce society's critical functionality thus making the system less resilient. [70]"

Although it would be difficult to design buildings resilient to pandemics, as adaptability and transformability are prerequisites for resilience, **architecture and urbanism possess the unique capacity to provide spaces in support of social resilience**. To prevent the disruption caused by social distancing, the spaces between buildings are ideal for social interactions such as conversation, greetings, children playing. In his book *Life Between Buildings*, Jan Gehl pointed to "life between buildings as a dimension of architecture, urban design and city planning to be carefully treated [71]." He draws attention to the fact that social contacts in public spaces have the characteristic of being spontaneous because people interact as a result of necessary or optional activities.

Past trends to regain outside public space will probably accelerate. As people spend most of their lives inside buildings, they tend to forget about life outside the buildings. According to the American Institute of Architects, "Americans spend 87% of their time inside buildings" [72]. Living outside the buildings is a main physical health topic. In the case of the Fitwel rating system for healthier buildings, the *Assembly Civic Design Guidelines* intends to enhance community connection to outer spaces by incorporating nature, making public spaces welcoming or making spaces for activity [73].

Working: telecommuting, size and dispersion

The immediate approach for office buildings are the air control strategies, such as air change, filtration and ventilation in the lobbies, staircases, elevators and offices, isolating strategies in the offices, such as partitions and cubicles, and distancing strategies. People distancing would be difficult in offices as this would either demand more space, but the reduction of the employees' present at any one time is feasible by taking shifts. The solution to decrease office population density is also possible with partial telecommuting.

The present COVID-19 pandemic accelerated the trend for telecommuting, also called teleworking or working from home. The idea appeared in California in the 1970s under the name of telecommuting, starting with the first generation of home working, the second generation with mobile working and now with the third generation of the virtual office [74]. The domain is regulated in the EU by the Framework agreement on telework of 2002 and, in the US, by the Enhancement Act of 2010. In 2019, 5.5% of workers in the US worked from home [75]. With the beginning of the COVID-19 pandemics, in April 2020, already 20% of Americans were able to work from home or remotely and were doing so [76]. This increase satisfies both employers and employees. A Gartner survey of 317 CFOs and Finance leaders in March 2020 showed that "nearly a quarter of respondents said they will move at least 20% of their on-site employees to permanent remote positions. [77]" According to a Buffer 2020 survey, 98% of the remote workers want to continue to work remotely for the rest of their careers [78], compared to 90% in 2018 and 99% in 2019. There is actually even more opportunity for development as a 2020 American paper calculated that "37 percent of U.S. jobs that can plausibly be performed at home account for 46 percent of all wages [79]."

One of the beneficial impacts of teleworking is on the environment: reductions in greenhouse emissions, fuel and energy usage. A 2018 analysis of telecommuting impacts on transportation in Chicago showed that telecommuting "has the potential to reduce network congestion and vehicular emissions [80]."

There is concern about the loss of productivity in teleworking as different studies showed mixed results. A survey led by the Japanese Research Institute of Economy, Trade and Industry (RIETI) during the COVID-19 pandemic concluded that globally "the productivity when teleworking is expected to converge towards productivity in the office [81]." There are also other concerns, such as "greater professional isolation and less organizational commitment on the days that workers worked entirely from home [82]." A 2007 meta-analysis of 46 studies concluded that "telecommuting had small but mainly beneficial effects on proximal outcomes, such as perceived autonomy and (lower) work-family conflict. Importantly, telecommuting had no generally detrimental effects on the quality of workplace relationships. Telecommuting also had beneficial effects on more distal outcomes, such as job satisfaction, performance, turnover intent, and role stress. [83]"

In the long term, reducing the size of offices, allowing better ventilation and more controlled accesses could be the architectural solution to pandemics. It would also require an urban approach with more dispersed office spaces in mixed-use neighborhoods.

Shopping: proximity and downscaling

Immediate measures that can be taken in shopping areas are air control strategies, such as air change, filtration and ventilation. The most secure shops seem to be the ones with direct access from the exterior as they may insure better ventilation and less potential contacts.

Distancing measures during the COVID-19 pandemic increased the importance of online shopping. In the US, deliberately buying online instead of offline increased, because of the COVID-19, increased by 32% in restaurant delivery/takeaway, 25% in hygiene products, food and drink delivery (e.g. from supermarket), 24% in household cleaning products, and 20% in clothing [84]. Although the trend will partially reverse, it will probably come back in the future. Among the most shopped products in 2018–19, clothing leads with 59%, followed by books, movies and gaming with 47% [85]. Shopping directly in stores will certainly continue for reasons that online shopping cannot overcome, such as touching or trying the product, shipping or enjoying experience [86]. Therefore, long-term measures for shopping have to be taken.

By the middle of the 19th century, most of the shopping in Europe took place either in open or covered markets or in shops with direct exterior access. Covered bridges, such as Ponte Vecchio, in Florence, may escape this general rule. By 1850s, about 150 covered passages (*passages couverts*) were built in Paris. They were streets restricted to pedestrian traffic, with glass ceilings, opened at the extremities. The 1852 Haussmann reform of Paris boulevards, the industrialization and serially produced goods with fixed prices led to the disappearance of those covered passages in favor of the *Grands Magasins* (department stores) such as Le Bon Marché (1852), Samaritaine (1865) or Galeries Lafayette (1896). These stores resembled the covered passages by the use of big central glass ceilings which now become central, not a linear circulation. Department stores were built worldwide, such as Harrods (London, 1834) or Macy's (New York, 1858). The covered passages later evolved in shopping malls, formed by a complex of buildings interconnected by pedestrian walkways. In the US they developed especially after the 1950s with the extension of the suburbs and the automobile culture. The improvement in lighting and ventilation techniques led to the development of the supermarkets, such as the US Astor Market, founded in 1915, self-service shops offering a wide variety of goods. Hypermarkets, closed boxy stores that combine a supermarket with a department store, started with Grand Bazar, in Belgium, in 1961, and with Carrefour, in France, in 1963.

Ironically, although one of the first hypermarkets appeared in France, they are almost absent in today's French cities' centers. Ten years after the first hypermarket in France, their occurrence in the cities was prevented by the 1973 Royer law which regulated the creation of shops over 1500 m^2 inside towns. Although they play a key role in the economic development, **hypermarkets are considered to be a cause of the city centers desertification and raise concerns about automobile transportation, energy consumption and waste removal**.

In the context of a health engaged architecture and urbanism, shop distribution in the cities should encourage proximity shopping and architectural configuration should be reconsidered with a return to smaller scale and more opened design.

Transportation: walking, bicycling, shared mobility and robo-taxies

Immediate measures which can be taken in public transport are the increase in ventilation, installation of HEPA filters and UV disinfection. The issue is of the utmost health importance as some papers claim that, for the case of New York for example, the subway system was the major disseminator of COVID-19 [87].

At the larger urban scale, containing virus spread in public transportation while not encouraging the environmental, health and social harmful automobile transportation could be addressed by promoting walking, bicycling, share mobility and new ways of transportation, such as robo-taxies.

The 1890s Garden City movement, the 1970s Intermediate Housing or 1980s New Urbanism and Urban Village movements already proposed walking or bicycling distances for the neighborhood scale. Large scale experiences have been conducted since, enhancing the bicycle mobility approach. Probably one of the most successful ones is the bicycle sharing system, which started with the white bicycle and white path proposed by the Provo movement in Amsterdam, in 1965. Bicycle sharing increases the efficiency of an urban public transport network [88] and have benefits for health [89]. The Vélib' (from 2017, Vélib' Métropole) in Paris is a large-scale success operation launched in 2007 which reached, in 2019, 175.000 subscriptions [90]. The Chinese bike sharing system, including the two largest operators, Ofo, launched in 2014, and Mobilke 2015, total over 50 million orders per day [91].

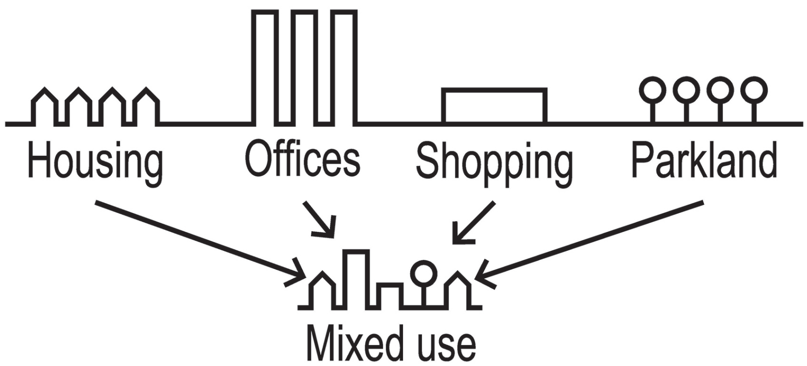
Car sharing is another new method of approaching urban transportation. The approach is not new, as the *Selbstfahrergenossenschaft* in Zurich dates from 1948 [92]. The introduction of electric vehicles started with the Renault Zoé for the Praxitele operation, in between 1997–1999, in Saint-Quentin-en-Yvelines, near Paris. Electric vehicle car sharing has a positive environmental approach by "reducing 29% of CO_2 emissions and increasing 36% electric vehicle adoption, when compared to the business-as-usual scenario [93]." In conjunction with UV disinfection systems in between rides, electric car sharing could be a public transportation alternative.

Robo-Taxi, also known as a Robo-Cab, self-driving taxi or a driverless taxi experiments started in 2016. A case study in Beijing estimates a good impact in lower energy consumption, zero tailpipe emissions, traffic decongestion and reduced health risks [94]. A theoretical simulation in Italy "propose that introducing a robo-taxi fleet of 9,500 vehicles, centered around mid-size 6 seaters, can solve traffic congestion and emission problems in Milan [95]." UV disinfection could be applied too.

In the long term, urban configuration should promote transportation by walking and bicycling that would better prevent pandemics than public transportation and reduce obesity and cardiovascular diseases compared to automobile transportation. Multimodal transportation and new transportation systems with shared mobility and robo-taxies could play an important role int the future with impact in pollution and also modified land usage, such as reduced parking footprints.

Higher scale: mixed use neighborhoods

To promote social contacts and transportation by walking and bicycling, neighborhoods should benefit from mixed use zoning aiming for partial self-containment by combining living with working, leisure, education and public space encounters.



CERTIFICATIONS FOR HEALTH ENGAGED ARCHITECTURE AND URBANISM

Green building or sustainable building certification started in 1990 with the Building Research Establishment's Environmental Assessment Method (BREEAM) and, in 1993, with Leadership in Energy and Environmental Design (LEED). The BREEAM certification concerns Health and Wellbeing, with topics such as Daylighting, View outdoors, Glare control, Indoor air quality plan, Indoor air quality Ventilation, Thermal comfort, Internal and external lighting, Indoor pollutants but doesn't address virus transmission. The LEED certifications concerns also the Indoor Environmental Quality (IEQ), with topics such as air quality performance, thermal comfort, interior lighting, daylight, quality views or acoustic performance; they do not assess virus transmission either.

A healthy building movement started in the 2010s with more recent health-oriented certifications, such as Fitwel, a joint initiative led by the US Centers for Disease Control and Prevention (CDC) and General Services Administration (GSA), launched in 2012, or WELL Building Standard from the International WELL Building Institute, launched in 2014. These standards were also not prepared for virus transmission.

The 2019 pandemic heightened the global awareness of the importance of healthy buildings. Fitwell reacted by Building Health for All in the Face of COVID-19 action, which published five resources among which is one that concerns architecture as "Leveraging Buildings to Mitigate Viral Transmission." The strategy to mitigate viral transmission relies on is limiting physical interactions, cleaning, handwashing signage, ventilation, filtration and humidity. The topics also appear in the guide "5 Ways to Optimize Buildings for COVID-19." To meet the new health requirements, in April 2020, WELL created a more than 225 member Task Force on COVID-19 and Other Respiratory Infections [96]. The taskforce is supposed to enhance the WELL Building Standard and to provide new resources and guidelines.

Most cities evaluation do not directly evaluate health issues, although they address some of the issues. Healthy cities are referred by the WHO European Healthy Cities Network with only general goals such as "a whole-of-city approach to health and well-being" and "human-centered urban development and planning." The Urban Low Emissions Development Strategy (Urban LEDS) is a project funded by the European Commission that addresses integrated low emission, building efficiency and resilient development but not health itself.

The LEED for Neighborhood Development certification already addresses health as a constant intent: preferred location within existing cities to avoid "the environmental and public health consequences of sprawl," access to quality transit to "reduce motor vehicle use, thereby reducing greenhouse gas emissions, air pollution, and other environmental and public health harms associated with motor vehicle use," transportation demand management "to reduce energy consumption, pollution, and harm to human health from motor vehicles by encouraging multimodal travel," bicycle facilities "to promote bicycling and transportation efficiency and reduce vehicle distance traveled. To improve public health by encouraging utilitarian and recreational physical activity," walkable streets "to improve public health by providing safe, appealing, and comfortable street environments that encourage daily physical activity and avoid pedestrian injuries," compact development "to improve public health by encouraging daily physical activity," connected and open community "to improve public health by encouraging daily physical activity," access to civic and public space "to provide open space close to work and home that enhances community participation and improves public health," access to recreation facilities "to enhance community participation and improve public health by providing recreational facilities close to work and home that facilitate physical activity and social networking," neighborhood schools "to promote community interaction and engagement by integrating schools into the neighborhood and to improve students' health by encouraging walking and bicycling to school. [97]"

OPPORTUNITIES AND THREATS

The present COVID-19 pandemic is one of the greatest challenges for world health and economics. **COVID-19 is not the first pandemic, nor the biggest and probably not the last.** The positive side of this pandemic might be the acceleration of some already started processes:

- **the recognition of the role of environmental impacts**, such as deforestation and destroying natural habitats, enabling zoonotic infections
- **a certain awareness that the financial sector should not solely emphasize economic growth but also prominently factor in environmental and health issues**
- **an acceleration of regaining the public space by social activities**
- **the architectural research of new living spaces typologies** in between single-family houses and apartment buildings, such as the intermediate housing.
- **the acceleration of promoting mixed-use neighborhoods** instead of the functional segregation of residential from commercial and industrial development and to moving away from automobile-based transportation by encouraging walking and bicycle transportation
- **accelerate advancements in transportation** such as bicycle, shared mobility and automation such as robo-taxies.

One of the biggest threats related to the current crisis that isn't immediately addressed by a strictly health approach are the social side effects related to social distancing and lock down strategies. These human tolls will become more obvious over time, unlike the more immediate economic impacts and will take some time to evaluate.

FURTHER DEVELOPMENT

Concerning future pandemics, in the absence of medical treatment, architecture and urbanism should be important means in preventing or limiting them. Although this was the main approach one century ago, with progress in medicine, architecture and urbanism ceased to be perceived as an important topic in human health.

Research financing in architecture is low compared to the role it could play in reducing the economic impact of hazards. A 2018 Interim Report Studies conducted by the National Institute of Building Science "found a national benefit of $11 for every $1 invested in mitigation [98]." Still, the research funding compared to the healthcare industry is striking. In the US, construction spending in 2016 was 6% of the GDP [99] but received only 4% of private research expenditures and less than 1% of federal research dollars. In contrast, the healthcare industry is worth 18% of GDP and receives 46% of federal research dollars and 21% of private research money [100]. In the EU, the European Institute of Innovation & Technology (EIT), does not finance research in architecture and urbanism directly, but through a program called Urban Mobility that finances mobility solutions to improve the use of urban spaces [101].

There is an urgent need to finance research for health engaged architecture with interdisciplinary teams comprising architects, urban planners, doctors, sociologists, anthropologists, and traffic engineers. This research should be based on an improvement in data on how the built environment can work toward limiting virus transmission.

Education system should also include health engaged architecture as a curriculum topic.

CONCLUSION

While architecture and urbanism incorporate technological and scientific innovations from different domains, they have the unique ability to organize space, one of the most limited resources. By organizing space, architecture and urbanism are the keystone not only in limiting further pandemics but also in playing an engaged role in human health.

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