Introduction to virus, bacteria, and fungi in the built environment

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1.1 Virus, bacteria, and fungi in the built environment

The Covid-19 outbreak of zoonotic origin—like MERS (Middle East Respiratory Syndrome) in 2012 and SARS (Severe Acute Respiratory Syndrome) in 2003—that some believe is the pandemic that humanity deserves (Harper, 2020; Gills, 2020) has led many (researchers and laymen) to try to understand a little bit more about microorganisms and the built environment. The objective of this introductory chapter provides basic information about both.

Viruses inanimate "things" without cells, bodies, or metabolism of their own that only become alive in the cellular organisms. Viruses use their host cells to multiply and produce progeny, clones of the infecting virus. Viruses can infect organisms and cause diseases, but they have also been part of evolution, even of humans. *Viruses do not just shape the human genome through natural selection, though. They also insert themselves into it. At least a twelfth of the DNA in the human genome is derived from viruses*. A specific example of the role of viruses is that the human placenta needs a special protein (syncytin-1) that originated from viruses *The protein that allows new cells to merge themselves with this layer, syncytin-1, was originally used by retroviruses to join the external membranes of their virions…* (The Economist, 2020).

Bacteria are more complex than viruses; they are cellular and surrounded by a membrane. Bacteria can live and reproduce almost anywhere on its own: in soil, water, and our bodies. For the most part, we live peacefully with bacteria—the colonies in our guts are helpful to us and strengthen our immune system. However, like viruses, bacteria can also harm us by replicating quickly in our bodies, killing cells.

Fungi, on the other hand, are more complicated organisms than viruses and bacteria—they are "eukaryotes," which means they are cellular and surrounded by a membrane but have a nucleus with its genes. Of the three aforementioned pathogens, fungal cells are most similar to animals in their structure (Cedars-Sinai, 2020). There are two main types of fungi: environmental, which are yeast and mold that often live in soil and do not generally cause infection in most healthy people; and commensals, which live on and in us and generally do not hurt us. Certain environmental fungi reproduce "spores," particles that can enter our body through the lungs or on the skin. These fungi can be especially damaging for people with weakened immune systems, as the fungi can spread quickly and damage many organs (Cedars-Sinai, 2020).

Based on the evidence of the Covid-19 pandemic, the virus will continue to circulate, spawning variants. Without a vaccine to prevent infection and to keep the number

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of virus low, the number of variant Covid-19 viruses will increase. The Serum Institute in Denmark, the world largest vaccine manufacturer, has documented that there will not be enough doses to inoculate the entire world until 2024 or beyond (Carr, 2020). Not even mentioning the alarming consequences of post-Covid syndrome includes exhaustion from small tasks, involving physical activity, cognitive complaints, and problems with the autonomic nervous system (The Economist, 2021). Of course that target could be met much sooner if the European Union decides to put enough pressure on pharmaceutical companies to produce sufficient vaccines in laboratories around the world (Pacheco-Torgal, 2021).

As it now widely known, the current rules based on hand washing and maintaining social distances are insufficient to protect populations from respiratory droplets emitted by people infected with Covid-19. This is due to the fact that the virus can infectious and remain in the air for long periods and travel long distances. Transmission via airborne droplets is aggravated in indoor environments with poor ventilation combined with high levels of occupancy and long periods of exposure. Several studies have shown that airborne transmission is the most likely mechanism to explain the pattern of social infection (Bahl et al., 2020; Van Doremalen et al., 2020), with the highest risk in indoor environments, particularly those with high occupancy levels and insufficient ventilation. Thus, there is an urgent need to use protective masks. It is therefore extremely important that the national authorities acknowledge the reality that the virus spreads through air and recommend that adequate control measures be implemented to prevent further spread of the SARS-CoV-2 virus, in particularly removal of the virus-laden droplets from indoor air by ventilation (Dietz, Horve, Coil, Fretz, & Van Den Wymelenberg, 2019). Targeted in-room humidification (between 40% and 60%) is another option to consider, because humidity can play a role in the survival of membrane-bound viruses, such as SARS-CoV-2 (Dietz, Horve, Coil, Fretz, & Van Den Wymelenberg, 2019). Appropriate building engineering controls include sufficient and effective ventilation, possibly enhanced by particle filtration and air disinfection, avoiding air recirculation (Morawska et al., 2020; Morawska & Cao, 2020). The Federation of European Heating, Ventilation, and Air Conditioning Associations made 15 recommendations to be applied in existing buildings at a relatively low cost to reduce the number of cross-infections indoors (REHVA, 2020). A summary can be found below:

1. Provide adequate ventilation of spaces with outdoor air.
2. Switch ventilation on at nominal speed at least 2 h before the building opening time and set it to lower speed 2 h after the building usage time.
3. At nights and weekends, do not switch ventilation off, but keep systems running at a lower speed.
4. Open windows regularly (even in mechanically ventilated buildings).
5. Keep toilet ventilation in operation 24/7.
6. Avoid open windows in toilets to maintain the right direction of ventilation.
7. Instruct building occupants to flush toilets with closed lid.
8. Switch air handling units with recirculation to 100% outdoor air.
9. Inspect heat recovery equipment to be sure that leakages are under control.
10. Adjust fan coil settings to operate so that fans are continuously on.

11. Do not change heating, cooling, and possible humidification set points.
12. Carry out scheduled duct cleaning as normal (additional cleaning is not required).
13. Replace central outdoor air and extract air filters as normal, according to the maintenance schedule.
14. Regular filter replacement and maintenance works shall be performed with common protective measures, including respiratory protection.
15. Introduce an IAQ sensor network that allows occupants and facility managers to monitor that ventilation is operating adequately.

Nevertheless, a recent article published in Nature claims that it is not clear how best to improve ventilation. As SARS-CoV-2 infection risk rises along with indoor CO_2 concentrations, maintaining low CO_2 limits (700 p.p.m. with lower limits) should be applied to indoor environments where people expel greater volumes of air (Lewis, 2021). Ironic as it may sound, the fact is that the Covid-19 crisis has pushed science into a situation that is drastically different from earlier work that were guided solely by mechanics and structural performance rules.

Pinheiro and Luís (2020) provided a historical overview on infectious diseases and how their behavior has contributed to changes in the built environment. Tokazhanov et al. (2020) also carried out a literature review and assessment on expert opinions on lessons learned from the COVID-19 pandemic to address a critical question to the community of building sustainability research*: What can we learn from the recent pandemic to modify the building suitability criteria and assessment methods that would promote better sustainable living conditions during such difficult periods affecting entire populations?* One problem of the Covid-19 pandemic is the need to support interactions between researchers of very different areas like civil engineers, architects, microbiologists, and epidemiologists (Prussin et al., 2020). Phelan et al. (2020) also recognized that the interplay between building energy efficiency or, more generally, building sustainability, and the health and productivity of the building occupants has not received much attention. He also commented on the fact that the research communities at meetings focused on sustainable buildings and indoor public health did not include individuals from the different fields. Unfortunately, one of the problems about the aforementioned lack of multidisciplinary research efforts has to do with the fact that usually funding programs are biased against it (Bromham, Dinnage, & Hua, 2016). That bias explains, in part, why innovative and cross-disciplinary investigations cannot find funding.

To cite examples, professionals of the built environment know about the structure strength of green building materials, but have no idea about if those materials are more prone to fungal growth when exposed to high humidity. High humidity, we should be reminded, will be more frequent under climate emergency scenarios that will bring, but much more, intense rainfalls (UNE, 2020; Labonté-Raymond et al., 2020). That narrow view is also reflected in considering ventilation. Building regulations associated with increased energy efficiency require low levels of outdoor air exchange, which strongly influences the indoor air microbiota with consequences to human health.

It should be no surprise that global health care and associated costs due to indoor air pollution for developed countries is near US $90 trillion. Health costs associated with indoor air pollution may be as high as US $9.4 billion in the US alone, leading to as many as 150,000 mortalities per year (Torpy, Irga, & Burchett, 2015). Kwan et al. (2020) recently studied how ventilation rates influence bacterial and fungal microbial community structure and concentrations in the indoor air of homes noticing that high and low air exchange rates (AERs) had little effect on the bacterial and fungal community concentration or structure of indoor air. Rather, the bacterial and fungal content of indoor air was dominated by microbes emitted from indoor sources. Further, those authors claimed that the data demonstrated a potential limitation of ventilation for impacting the ecology and concentration of indoor air bacteria and fungi in occupied homes.

Unfortunately, human health is not on the top of building regulations concerns, and one reason for that is the fact that the curricula of civil engineering and architecture show a most worrying gap about those issues. Horve et al. (2019) recalled anecdotally the fact that, when architects describe “healthy building” principles, they routinely speak of access to daylight and outside air, and this is supported by the prioritization of daylight in building performance rating systems. Carmichael et al. (2020) referred to the need of considering health impact in future building regulations. On this context, it is worth seeing the summary of the healthy building concept and how it affects the physical, mental, and social well-being of occupants presented by Awada et al. (2021). Recent studies show that a healthy environment is crucial to maintaining the strength the immune system (Haahtela, 2019). It is no wonder that traditional nonhealthy built environments have been identified as a problem in the context of the Covid-19 health crisis in which many more people spent more time indoors. The numbers are very clear and show that the general population in North America and Europe already spent on average around 89% of their time indoors (McGratha et al., 2017). To make things worse since Covid-19 came along the confinement raised that percentage to as much as 100% at least to people belonging to risk groups. It is important to remember that a healthy indoor microbiome is not only one that does not make us sick, but may also promote well-being. Buildings of the future should, therefore, also be designed to promote the presence of beneficial microbes and by reducing exposure to harmful ones.

In order to achieve the goal of developing a healthy built environment, the most relevant factors to monitor must be identified. This, in turn, requires the definition of a healthy microbiome and other factors such as the building type. Still it is unclear which microbial component we need to measure. For instance, some of the strongest negative health associations have been found with visible mold growth (Dannemiller, 2019). The total health care system costs due to mold and dampness in indoor environments were estimated to be around $1.84 billion and $18.4 billion annually in Canada and the US, respectively (Hostland, Lovegrove, & Roberts, 2015). Keenan (2020) have reminded readers that times of disaster do intensify our biophilic behaviors and also highlight the fundamental values associated with investments in public space and the natural environment. Also, according to Awada et al. (2021), if we are to achieve healthy buildings, we *must have* a holistic, interdisciplinary research framework through which experts in building science, health, data science, and artificial intelligence collaborate in a coordinated effort. This book was written having that goal as a guiding compass.

1.2 Outline of the book

This handbook provides an updated state of the art about the presence of virus, bacteria, and fungi in the built environment.

Part One encompasses an overview on basics of microbiology and also different cases of pathogenic contamination (Chapters 2–8).

Chapter 2 starts this book by addressing the difficult task, that is, to introduce in a comprehensive manner the issue of virus, bacteria, and fungi to the professionals that work in the built environment. The chapter covers many issues from the diversity of *bacteria* and *archaea, passing by the p*rokaryotes and protozoa in the indoor environment to fungal aerosols.

Chapter 3 is concerned with the case of environmental, waterborne opportunistic pathogens that are present in drinking water.

Chapter 4 reviews the influence of different metallic and polymeric materials on biofilm formation in plumbing systems. A summary on the most commonly used techniques to assess and evaluate biofilm formation on different surface materials is also included.

Chapter 5 provides an updated review on the accounts of black fungi into the built environment and describes the most common types of extremophilic environments from where they have regularly been isolated. A discussion about current hypothesis for the entry and colonization of black fungi into the indoor environment, as well as their potential impacts on human health and on the biodeterioration of man-made materials, is included.

Chapter 6 presents a case study that have analyzed the fungal air burden existing in the cloister of the Old Cathedral of Coimbra.

Chapter 7 covers the causes and origins of bacteria bioburden, the types of transmission, and the most common isolated bacteria, in both indoor and outdoor environments.

Chapter 8 reviews airborne bacteria and the sick building syndrome (SBS). It also cover the diagnosis, treatment, and prevention of SBS.

The strategies for monitoring and control of indoor pathogens are the subject of Part Two (Chapters 9–14).

Chapter 9 identifies different methodologies applied to assess fungal contamination in healthcare environments, also describing the most reported fungi in these environments.

Chapter 10 discusses the impact of molds and health; tools for measuring fungal contamination; major studies proposing thresholds; state guidelines for acceptable thresholds; and the issues involved in setting thresholds for risk.

Chapter 11 focus on scenarios related to indoor safety monitoring. The following aspects relevant to indoor COVID-19 protection will be considered: (1) checking whether visitor wears protective mask, (2) body temperature check, (3) social distancing, (4) limited person number indoors, (5) automatic touch-free hand sanitization, and (6) tracing contacts involving infected persons. As research outcome, several case studies developed at the University of Niš, Faculty of Electronic Engineering in Serbia, will be presented.

Chapter 12 provides valuable information on the ventilation strategies for the maintenance of healthy indoor air quality in hospitals.

Chapter 13 is related to the development of hydraulic lime mortars with nanoparticles having antifungal properties.

Chapter 14 closes Part Two with a closer look on a galvanic-based antifungal protection system.

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