Vol. 13, No. 4, 500-513, https://doi.org/10.22712/susb.20220036

INTERNATIONAL JOURNAL OF
SUSTAINABLE Building Technology and Urban Development

pISSN 2093-761X · eISSN 2093-7628

Design of learning spaces in the post-pandemic era

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Received: 12 December 2022
Accepted: 19 December 2022

ABSTRACT

During the pandemic, online education has been adopted at all levels of education, and face-to-face lessons have started to be given with the reduction of the effects of the pandemic. For this reason, educational areas should be reconsidered, and online learning and face-to-face teaching should be supported. Various measures and design strategies can be taken to reduce the risk of infection in closed areas have been mentioned in the literature. This article provides comprehensive research on measures that can be taken to reduce the risk of disease and maintain a healthy indoor environment in the classroom. It also offers conceptual approaches for engineers, designers, and architects in the building construction industry to adopt these strategies in course space design. These design strategies were gathered under three headings and examined, and techniques that could be applied were determined by considering the needs of nature, technology, and society.

Keywords: learning space design; nature; technology; society; post-pandemic

Introduction

The changing socio-economic life is getting difficult living conditions, and urbanization requires re-questioning and re-arranging the life we live. Today, cities are rated primarily for their quality of life. On the other hand, quality of life is a phenomenon that contains many concepts together. While creating the concept framework, boundaries are determined by today's living conditions and technology. With its different shapes and appearances, this framework has surrounded almost every area of our lives today.

The starting point of the concept of sustainability is preventing environmental problems that arise in parallel with economic and technological developments and the protection of the ecosystem. And sustainable development is the world view that aims to ensure economic development by using environmental values and natural resources with rational methods, considering the rights and benefits of present and future generations. The sustainability concept must be accomplished through urban planning [1]. It is a living thing that can be achieved by sustainable solutions like housing, transportation, historic urban building heritage, disabled and socio-economic disabilities in cities, cultural integration, health, city management, etc. [2]. According to Campbell, "Campbell's planner's triangle," there are three fundamental priorities of planning three pillars which are "economic viability," "environmental protection," and "social equity" [3]. Although these three conflicts are important, no foot can exist alone. While

triangular planning represents the key objectives, the center of this triangle is sustainable development. Managing each pillar of sustainable development is necessary to prevent economic, social, and environmental disasters.

Today, with the COVID-19 pandemic, negative effects have occurred on public health, the economic, social, and cultural activities. In addition, environmental impacts such as indoor air quality problems and energy consumption in schools have also been observed due to the pandemic. The epidemic seriously affects outdated public buildings and especially inadequate educational buildings. Along with the online continuation of the lectures, unforeseen disruptions occurred in the planned activity due to the lack of technological infrastructure. Compared to face-to-face education, the efficiency achieved has created great debates in the education community and has been the research subject.

Şahin [4] examined university students' views on distance education during the COVID-19 pandemic; 47% of the participants stated that they had problems accessing the distance education system, 38% did homework and noted that the projects and presentations were useless. In addition, 30% of the participants declared that they had communication problems with the instructors throughout the process. Li et al. [5] analyzed that the number of teaching platforms and the quality of the lessons were inversely proportional and that there was a negative relationship between the situation of the problems students encountered in online learning and their effectiveness.

Universities are among the high-density structures that host large numbers of individuals every day. Therefore, after the reopening of schools, although numerous studies have shown that this reopening does not increase the risk of COVID-19 outbreak, it is known that the risk of spreading the virus in such buildings is high [6]. Numerous national and international protocols and guidelines have been published to minimize the risk of contamination and protect public health [7]. The measures applied inevitably affect the indoor environment, which is an important factor in individual and social health.

When the behaviors of students returning to school are examined with the reduction of the relative effects of the pandemic, while 97.2% of students thought that their school adjustment was high, 45.2% of teachers pointed out that students' school adjustment was moderate after the pandemic [8]. It has been observed that the students who have been away from their schools for about a year and a half due to the measures taken experience adaptation problems and anxiety problems in their education when they return with drastic measures. It aims to eliminate students' adaptation problems with measures such as vaccination activities for young individuals, masks, pedagogical supports, reduced class hours, and extended breaks. In addition, it is aimed to eliminate alienation from society with increasing guidance activities.

The indoor environment concept framework needs to be reconstructed with all these developments. The building design concept is diversified with technological developments, changes in city living conditions, and new needs. This concept should also be shaped according to the needs of the period. It continues to change and differentiate in line with the conditions and requirements of the day.

Understanding the transmission methods of COVID-19 is an important tool in reducing the effects of such diseases. The disease is transmitted from person to person, mainly through droplets at less than two meters. In

addition, droplets released by sick individuals through coughing and sneezing are transmitted because of contact with other people's hands and then bringing their hands to their mouth, nose, or eyes. The virus, which clings to particles suspended in the air, thus hangs in the air for a longer period and can be transmitted through the air by being inhaled by someone else.

Therefore, the prevention of infectious diseases should be encouraged in indoor design. According to the hospital ward design tried by Florence Nightingale, natural daylight and cross ventilation are a method to reduce infection and transmission in hospitals [9]. The pandemic has greatly affected economic, social, and human life and has radically changed individual social habits worldwide. Due to COVID-19, people's awareness of infection control has increased exponentially worldwide. Using proven tools, societies can be reshaped, social, economic, and human strategies can be developed, and steps can be taken for the new normal. Due to the pandemic caused by the COVID-19 virus, building requirements can change rapidly, as seen in 2020 and 2021 [10]. Design strategies for infection prevention, prevention and control should be developed for all indoor spaces.

With the rapid spread of the COVID-19 pandemic, it has become necessary for educators worldwide to continue their education processes with modern and advanced technology on various platforms. In this process, many technological solutions have been tried to ensure the continuity of learning. The possible forms of education that will emerge in universities after the pandemic are largely determined by the behavior of all actors in the education sector.

According to Adedoyin and Soykan [11], self-interest is a major challenge facing online education. The practice has an important effect on the learning process. The learning process cannot reach its full potential until students apply what they have learned. Some online courses are theoretical and do not allow students to practice and learn effectively [12]. A study determined that students cannot balance their work, family, and social lives in an online learning environment [13]. According to the study conducted by Adnan and Anvar on students [14], 78.6% of the participants declared that traditional courses are more effective than online learning. [15] determined the perception of face-to-face education and online learning by conducting a survey with students and teachers during the pandemic. According to this study, face-to-face learning is perceived more positively than online learning in terms of social presence, interaction, satisfaction, and overall quality.

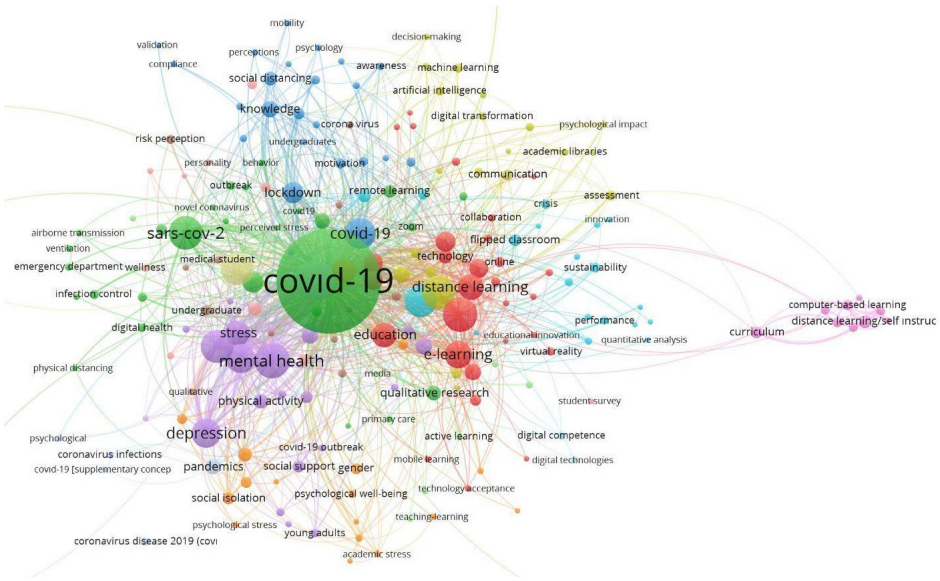
Although it was concluded that online lessons are convenient in terms of time-saving, both teachers and students stated that they are less effective than in-class learning methods [16] and explored the advantages, limitations, and solutions of online education for private university students in Indonesia. According to this study, besides the benefits, such as being able to rest at home with online learning and not being limited by space and time, disadvantages, such as low concentration and internet problems, were mentioned. While online education is an important factor in continuing education during the pandemic period, it has many issues, according to the qualitative surveys made with students and teachers. With the decrease in the effects of the pandemic, universities decided on face-to-face education. However, it is a known fact that the risk of infection continues during the post-pandemic period, which we describe as the new normal. For this reason, education areas should be reconsidered, and face-to-face education

should be supported with online learning. Several measures and design strategies that can be taken to reduce the risk of infection in closed areas are mentioned in the literature.

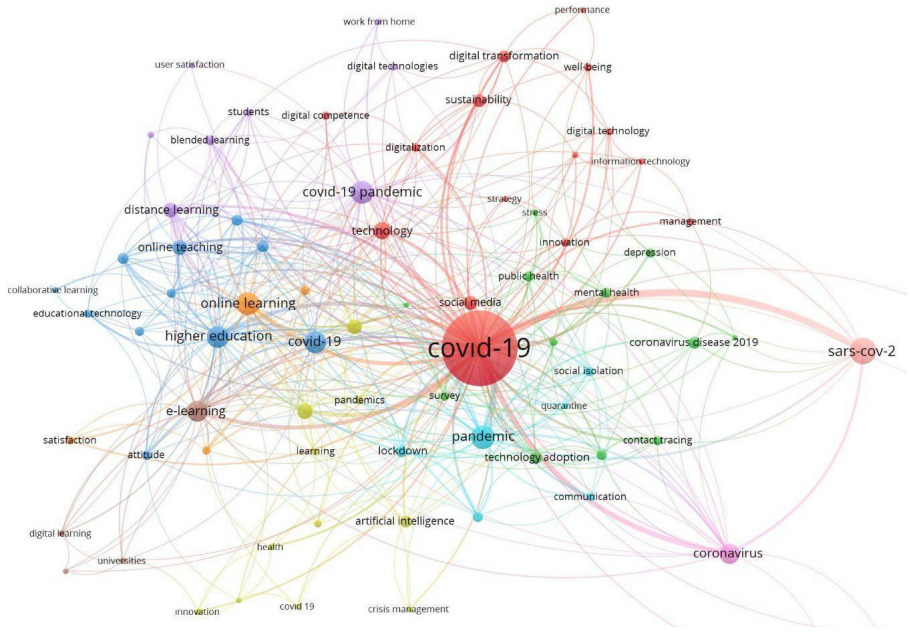
This article presents comprehensive research on the quality of a healthy classroom indoor environment and the measures that can be taken to reduce the risk of infection. It explores and discusses solutions to transform the classroom into a more beneficial space. This article aims to provide a comprehensive review of design strategies that can be applied to reduce the transmission of COVID-19 and achieve healthy classroom environments. However, this study discusses design strategies through Campbell's sustainable development triangle. The aim here is to find an answer to the pandemic problems that may be encountered in the future under the titles of economy, society, and nature, which are the pillars of sustainable development. In addition, technology, which reflects economic developments, has been evaluated instead of the title of the economy and is a new interaction point necessary to have a healthier classroom environment. It also offers for engineers, designers, and architects conceptual approaches to adopt these strategies in school classroom designs in the building construction industry.

Methodology/ Bibliometric analysis

This study searched articles published on the Web of Science (WOS) by keywords to develop a detailed literature review about healthy buildings and their systems. The literature review collected data from different sources and then analyzed them. VOS viewer [17] 1.6.18 software was used to visualize the literature trend on design strategies and healthy buildings about COVID-19 (Fig. 1a, 1b). The information of the documents meeting the requirements, such as publication year, language, journal, title, author, institution, keywords, document type, abstract and citation numbers, were recorded in text format and transferred to the software. Figure 1a created a network with 374 keywords by researching healthy buildings in WOS and the COVID-19 pandemic. In Figure 1b, technology is one of the 3 main concepts obtained from COVID-19 universities and beneficial building research. WOS search was carried out with the word's "sociology" and "environment," In this figure, a network was created with a threshold of 120 keywords. Figure 1a, a network was made with 374 keywords by researching healthy buildings and COVID-19 pandemic keywords in WOS. In Figure 1b, which is a network of 120 keywords, WOS research was conducted with the keywords "COVID-19", "universities," and "healthy buildings." And three main concepts, "technology," "sociology," and "environment," were obtained because of this research. The size of the nodes found in these graphs indicates the frequency of occurrence. Curves between nodes represent keywords that are together in the same article. The shorter the distance between two nodes, the more the two keywords are found together. Font size represents the frequency of occurrence [18]. According to Figure 1a, "COVID-19", "technology," "society," and "nature," and secondary concepts related to these primary concepts emerged the most.



(a)



(b)

Figure 1. (a) Network visualization based on keyword co-occurrence analysis on COVID-19 and healthy buildings, (b) Network visualization based on keyword co-occurrence analysis on COVID-19 and lecture space.

Design Solutions

This study reviewed related studies through search engines such as WOS and Google Scholar to obtain scientific and applicable design strategies for universities in the post-pandemic period. Studies were reached using research methods such as literature review, expert opinions, questionnaires, etc. In terms of research content, studies on contamination prevention and design strategies were examined. These studies focus on spatial and social distance,

ventilation, lighting, thermal comfort, technology, touch-free interfaces, and artificial intelligence. During the quarantine period, people locked at home had to spend all their daily activities, such as eating, working, socializing, and leisure time in closed environments, so the focus should be on the comfort of life in the post-pandemic period. In summary, this study divides the design elements for lecture spaces in the post-pandemic period into three dimensions: "nature," "technology," and "society," together with the keyword "COVID-19", according to human needs. According to these three dimensions determined through the literature review, 17 publications were analyzed, and the design strategies were shared in Table 1.

Table 1. Design strategies in the post-pandemic era for closed spaces

	Nature	Technology	Society
[19]	Expanding horizontally	Adaptive reuse	
	Fewer Density Cities	Lightweight and adaptable structures	
	Decentralization	Hygienic building materials	
	Urban Farming	Digital transformation	
	Fewer cars, more cycling and walking	Ability to work from home	
	Self-sufficient strategies	Artificial intelligence and touchless technologies	
	Refocusing on green spaces		
	Low-rise buildings		
	Better air quality		
[20]		Innovation	Respect to Culture
		Continuing to evolve virtual work	
		Digitally supporting collocated work	
[21]	A sustainable workplace	Broadband speed and reliability	Quality of life
	Remote working can save energy and emissions	Air-ground connectivity	
	A sustainable future workplace		
	Modular buildings		
	Design for reuse		
	Healthy buildings		
	Convergence		
	Building certifications		
[22]	Supply fresh air		Social contact
	Natural Ventilation		Rising happiness
	Sunlight		Sense of comfort
	View		Mental health
			Preserve social distance
[23]	Daylight	Smart building technology	Social interactions
	Thermal environment	Touch-free interfaces	Physical distancing
	Acoustic environment		

Table 1. Design strategies in the post-pandemic era for closed spaces (Continue)

	Nature	Technology	Society
[24]	The decline in car-based transportation	Information-based construction management methods	
	Increase in lightweight structural systems	Increase in off-site construction and engineering	
	New materials for performative insulation		
	Revisions in density and compact design		
	Decentralized building systems		
[25]	Sanitation	Dispersed technology	Social distance
	Casual eating areas	Quality internet access	
	The connection between indoor and outdoor	Hybrid teaching	
	Adequate ventilation		
	Comfortable and diverse furniture		
[26]	Environment	Digital lectures	Supporting cognitive and social development
	Naturally across campus		Collegiality
			Real interpersonal engagement
[27]	Environmental Quality		More sensitive to proxemics and privacy aspects
	Management and governance		
	Thermal comfort		
	More Natural Sunlight		
	Enhancing Air Ventilation		
	Furniture adaptations		
	Internal Green Spaces		
[28]	Circadian regulation		Support positive social interactions
	Visual and thermal comfort		
	Window views, spatial variety and privacy		
	Natural ventilation		
	Connection to nature		
[29]	Fundamental index-scale and interrelation		
	Function Spaces-facilities and emerging needs		
	Spatial Structure-openness and division		
	High-quality private outdoor space		
	Much division and as much openness		
	Hygiene zone close to the entrance		

Table 1. Design strategies in the post-pandemic era for closed spaces (Continue)

	Nature	Technology	Society
[30]	Eliminate the modern design trend	Smart And Sanitize Entryway	
	Acoustically isolated room	Smart cleansing	
	Nature	Digital Pre-design System	
	Biophilic design		
	Indoor Quality		
[31]	Improving ventilation systems	UV-based technologies	More human-centered designs in the future
	Ventilation-related interventions	Biofiltration technology	
[32]	Air-safety system	Zero-touch system	
	Home comfort system	Sanitization and purification system	
	Design for social distancing		
	Design to enhance natural ventilation		
	Design to Enhance Daylight or Sunlight		
	Design with adaptive finishing materials		
	Flexible design with sustainability features		
[33]	More green spaces	Support online work	
	More access to nature	Flexible and adaptable design solutions	
	Furniture		
	Noise and pollution		
[34]	Air filters	Plasma technology	
	Wall floor treatments	Bipolar ionization	
	Nonporous material	Smart construction material	
	Ultraviolet radiation		
	Indoor plants		
	Open space		
	Natural ventilation		
	Antimicrobial paint		
	Green wall		
	Air ionization		
[35]	More flexible space	Smart and contactless home	Retrace of communal spaces
	Outdoor Connection	Self-reliant homes	
	Urban farming		

Nature

Dense urban areas need adaptive changes as they are vulnerable to spreading airborne diseases like coronavirus. Urban facilities, public green spaces such as parks and gardens, and the importance of open-air recreation areas came to the fore during the pandemic. After the quarantine, these public spaces became widespread and contributed to the physical and mental health of the users. In addition, semi-open areas, terraces, and balconies have positively

affected people's tolerance for long-term quarantine [22]. Green spaces integrated into buildings, including roof and vertical gardens and green walls, also help meet users' physical and mental needs [36]. Perceived stress during the COVID-19 pandemic has emerged as an important factor that cannot be ignored. It is known that having sufficient daylight and buildings with biophilic properties positively affect perceived stress [37]. Indoor air quality has been one of the most important criteria, especially during a pandemic. It is a well-known fact that using decentralized mechanical ventilation alongside using natural ventilation helps reduce transmission [38]. In addition to the inadequate natural ventilation in schools and high concentrations of indoor air pollutants in classrooms, it will provide super-spreading environments for airborne microorganisms. Therefore, lecture spaces should be used mechanical ventilation [39]. According to [40], high ventilation rates reduce the risk of infection in a school environment during the COVID-19 period in Italy. [41], according to their study on the effect of ventilation on the distance of COVID-19, the virus spreads much faster in the indoor environment, and displacement ventilation systems also reduce the risk of exposure to the virus.

Technology

Science and technology have played a vital role in the fight against COVID-19 to prevent transmission and contain its spread. Facial recognition cameras, robots, uncrewed aerial vehicles and artificial intelligence were used to detect infected patients in the early stages of the pandemic [42]. In addition, many researchers use artificial intelligence and machine learning to detect and prevent infection.

The measures against the COVID-19 pandemic are not limited to the health sector. One of the areas where technology is used is indoor places where people spend their time, especially during the COVID-19 quarantine period. The materials used in the design of the structures can be a source of infection. On surfaces close to room temperature, which is determined as 20-25°C, coronavirus survived for 2-28 days on steel surfaces, 0.17-1 days on copper, 0.08-0.5 days on aluminum, 1-5 days on wooden surfaces, 1-5 days on fabric, and 5 days on ceramic surfaces [43]. Accordingly, indoor air quality and the spreading viruses and bacteria can be prevented using technology in building materials used in indoor designs. Copper alloys contain antiviral and antibacterial ions that can kill more than 99.9% of germs in just two hours [44]. Therefore, copper can be recommended as a much better building material than other traditional materials for post-COVID-19 buildings. In addition, bacterial growth can be prevented by applying antibacterial paints to interior walls [34].

Both natural and mechanical ventilation solutions can improve the supply of fresh air inside buildings [45]. However, when the differences between mechanical and natural ventilation are evaluated in terms of indoor air pollutants, it is seen that the health status of those living in mechanically ventilated houses is better, and their health is greatly improved. Considering IAQ conditions, mechanical ventilation can reduce indoor particulate concentrations in residential buildings [46]. For example, when natural and mechanical ventilation and air quality measurements are compared, pollutant concentrations in schools with mechanical ventilation are lower.

Besides these issues, ultraviolet radiation technology, air-cleaning plants, bipolar ionization, disinfectant fogging

systems, mechanical and electrical filtration, adsorption, ozonation, photolysis, photocatalytic oxidation, biological processes, membrane separation, plasma-catalytic hybrid systems, hybrid ozonation systems, and biofilters and bioreactors, eco-friendly air-purification techniques can be effective for healthy building [34].

Society

According to Maslow [47], there is a hierarchical order of human needs, and this order is a pyramidal structure that varies according to the most and the least important needs. In order of priority, these needs are physiological, followed by security and belonging. The shelter is essential for safety and social and personal satisfaction in this pyramid. Besides, it is the place to feel secure and store energy for maintaining a healthy and quality life. Therefore, shelter is the most effective assurance of human existence [5]. The indoor environment is necessary, referring to a structure resistant to natural disasters and providing shelter for the individual and qualified life. Not only is adequate accommodation, but the goal is to make building an environment more physically healthy for people the essential characteristic of buildings.

Buildings should aim not only to provide adequate accommodation but also to create a healthier environment for people. Following the physiological and safety needs, the third level of human desires is social, including feelings of belonging. A human emotional condition for interpersonal relationships, affiliating, connectedness, and being a part of a group is called belongingness. During the COVID-19 period, due to social distancing, it was not easy to meet this need [48]. People who communicate online with friends and relatives try to reduce their anxiety and fears about COVID-19 [49]. Tolacı et al. [50] investigated the effects of changes in people's emotional states on architectural spaces throughout the pandemic's quarantine phase. According to this research, design criteria and elements should be chosen to rebuild the same area in order for the change to be beneficial.

According to the World Health Organization (WHO), the global prevalence of anxiety and depression increased by 25%. Many factors have contributed to this increase. The unprecedented stress caused by social isolation from the pandemic, loneliness, fear of infection, fear of death for oneself and loved ones, unemployment, and financial worries, have also led to anxiety and depression.

So, Maslow's hierarchy of needs, COVID-19 management activities could address the entire society's needs, especially if they are integrated with social determinants of health [48]. The social determinants of health must be integrated with Maslow's hierarchy of needs when considering responses to the pandemic. These factors include economic, social, and political policies and systems [51]. Aligning decisions with these factors will ensure the approach is based on "Society Needs." [48].

Conclusion

In the wake of COVID-19, universities worldwide have been closed for study on campuses. Many have transitioned to online course teaching and learning for the semester. Universities suspended study abroad programs. Several

universities have closed to international students. Also, most universities in the Erasmus area closed for a semester or even a year [52]. The shift to online classes is not as simple as it appears, as there are many issues with delivery, staff expertise, and student participation. The pandemic forced the adoption of online education. From a student perspective, the pandemic learning environment is challenging [53]. In addition to these issues, some courses have not adopted online learning.

Distance learning has some difficulties [54, 55]. Students can feel lonely and helpless because of the absence of direct contact. Distance learning has psychological, organizational, technical, and technological difficulties. The psychological problems are associated with the lack of direct communication, alienation and isolation from the student community and anxiety and concerns about the education process [56].

According to the Council of Europe, there are 4 purposes of higher education. The first one is preparation for sustainable employment. The second purpose is the preparation for life as active citizens in democratic citizenship. The third one is personal development. The last is developing and maintaining a broad, advanced knowledge base [57]. The current conditions have required the concepts of social solidarity, civic spirit, participation, cooperation, and a commitment to the public good to be rethought for higher education [57].

Education has been conducted online for almost two years in many countries despite these difficulties. With the end of the emergency phase of the pandemic, schools have switched to face-to-face education. However, this does not mean that we are completely cured of the disease. Therefore, precautions should be taken, and strategies should be developed. In light of the studies that have been done, the spread and transmission of the disease can be prevented with the design decisions taken after the pandemic. These design strategies have been gathered under three headings and examined, and techniques that can be implemented have been determined by considering the needs of nature, technology, and society.

Strategies for nature; Natural and mechanical ventilation, which relates to indoor air quality, is among the most important criteria. In addition, thermal comfort parameters, acoustic, lighting, and thermal solutions should be reconsidered. Internal green spaces, classrooms connected to nature, breathtaking living walls, division for the social distance in class and comfortable and diverse furniture should be rethought for lecture spaces.

Strategies for technology; creative and useful smart solutions are being developed day by day to reduce the spread of the epidemic. During the pandemic period, it has been observed that digital infrastructure is of great importance in terms of public health management. The vaccines produced with the use of technology have been protective against diseases. In addition, people have met their social needs by using technology to socialize. In terms of education sustainability, distance education continues by using interactive technologies. The place of technology in our lives will be of great importance in the post-pandemic period. In lecture spaces, new hygienic materials should be produced using smart building technologies, touch-free interfaces, UV-based and biofiltration technologies, and, most importantly, solutions that will support online studies.

The most important strategies for society are to maximize the benefits of both remote and collocated study in the classroom. More human-centered designs should be implemented to support social contact, a sense of comfort,

social interaction, real interpersonal participation, and societal needs that support cognitive and social development.

This article provides an opportunity to assist architects and designers in seeking solutions to environmental, technological, and social problems within the lecture area. It guides researchers as a checklist for strategies to consider when constructing or redesigning learning spaces. Finally, it is expected that the problems mentioned above caused by the COVID-19 pandemic in education areas will turn into a general learning process against such issues that may be encountered in the future. For this reason, education areas should be redesigned to face these challenges and learn lessons from the current period.

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