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Designing Learning Environments in Response to Pandemics: a Comparative Analysis for COVID-19 Best Practises Schools Interventions

Merna Mikhaeil, Asmaa Hasan, Tarek Farghaly

(Demonstrator Merna Mikhaeil, Faculty of Engineering, Alexandria University, Alexandria, Egypt, eng-merna.mandy1318@alexu.edu.eg)
(Lecturer Asmaa Hasan, Faculty of Engineering Alexandria University, Alexandria, Egypt, asmaa.elsayed@alexu.edu.eg)
(Professor Tarek Farghaly, Faculty of Engineering, Alexandria University, Alexandria, Egypt, tarek.farghaly@alexu.edu.eg)

1 ABSTRACT

The design of learning environments has a significant role in students' health and well-being, particularly in the light of the COVID-19 pandemic which has highlighted many challenges concerning the quality of learning environments in our schools, especially elementary schools. This emergency caused a massive closure of schools and around 1.2 billion students were unable to learn in their physical learning environments during this period. Before developing medications for the epidemic, one solution to limit the infection was transforming our learning environments and adding layers of protection to ensure healthy and safe spaces for students.

This paper aims at investigating the design principles of healthy learning environments according to AIA strategies for safe reopening schools which can be included in providing healthy indoor environmental quality, integrating nature with the learning environments, and providing safe contact in the learning environments. Then, a comparative analysis will be conducted on three existing schools which have succeeded to limit infection transmission and transform into healthy learning environments during COVID-19. Finally, the paper provides a framework and recommendations for the designing of future healthy learning environments to face any potential pandemic which may occur in the future.

Keywords: COVID-19 Pandemic, AIA Strategies, Schools Interventions, Designing Learning Environments, Healthy Learning Environments

2 INTRODUCTION

The COVID-19 pandemic has proven that a catastrophe does not always face a recognized enemy. The enemy might be hidden with disastrous impacts (Goniewicz et al., 2020). The most immediate effects of COVID-19 are on physical health, but it also has severe effects on social and emotional functioning. Globally, the COVID-19 pandemic has had a negative impact, particularly in the field of education, as the rapid spread of the virus has forced governments to take extreme actions, including the total or partial closure of existing schools in over 190 countries as shown in Fig. 1, in an effort to prevent the spread of the disease and limit its effects. By the middle of May 2020, more than 1.2 billion students were unable to learn in physical learning environments (Spitzer, 2021).

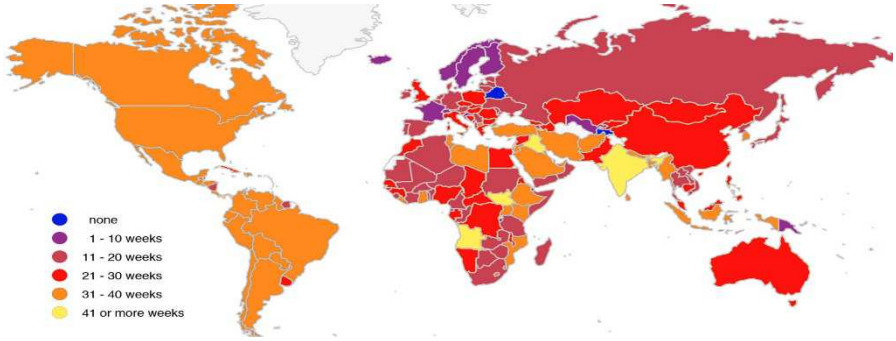

Fig. 1: Location and duration of school closures by country, (Spitzer, 2021).

School closure was the only solution to protect students from the COVID-19 pandemic because schools are not designed to adapt to any urgent crises or health pandemics for the following reasons:

- Current schools neglect social isolation; instead, schools have a large density of students and were designed to be a place where students can interact with each other (Van Doremalen et al., 2020), so keeping social distancing will lead to difficulty because the number of classrooms in existing schools is not sufficient to meet the whole number of students while maintaining social distancing.

ISBN 978-3-9504945-2-5. Editors: M. SCHRENK, V. V: POPOVICH, P. ZEILE, P. ELISEI, C.BEYER, J. RYSER, H. R. KAUFMANN – Ljubljana, Slovenia

- The surfaces and furnishings in existing schools were not designed for hygienic purposes; rather, they were only designed with sustainability and environmental concerns as priorities (Khanam et al., 2006). In addition, hygienic strategies in existing schools are not enough to face the pandemic; students must also physically push or touch surfaces to operate doors, windows, lights, etc., which increases the risk of COVID-19 spreading among students (Chin et al., 2020).
- The ventilation rates of existing schools are only 3.44 dm3/s/person, which is insufficient because the minimum needed ventilation rate for schools must be 8.5 dm3/s/person to be able to fight infection transmission according to the Dutch Building Code (Blocken et al., 2020).

Because of these problems, learning environments were not healthy enough to adapt to the COVID-19 pandemic and were obliged to be closed. During this period, education was provided through distance learning. Although distance learning offers a secure way to ensure learning continuity while protecting students, there is no substitute for physical classrooms because of the drawbacks of distance learning, like the difficulty of using distance learning for younger students. Also, distance learning can lead to social isolation by keeping students away from physical activities that are essential for learning, growth, and innovation. This will lead to issues related to mental health (Jiao et al., 2020). Consequently, AIA, CDC, and WHO started preparing strategies for the existing schools to reopen securely, and for future learning environments, the design principles won't be similar because health factors will be required to add safety layers to adapt to any pandemic that may happen in the future (CDC, 2021).

3 METHODOLOGY

This study is an exploratory study that is based on three main sections, as shown in Fig. 2. The first is a literature review presenting the relationship between designing learning environments and infection transmission control, and the importance of being healthy future learning environments. The research then investigates the design principles of healthy learning environments according to AIA strategies for safe learning environments. The second section presents a comparative analysis conducted on three existing schools that have succeeded in applying AIA strategies to their schools to limit infection transmission and transform them into healthy learning environments during COVID-19. According to these findings, in addition to the researches conducted during COVID-19, we can finally devise a framework and a checklist of measures for designing future learning environments that will be constructed post-COVID-19 to be resistant to any potential pandemic that may occur in the future.

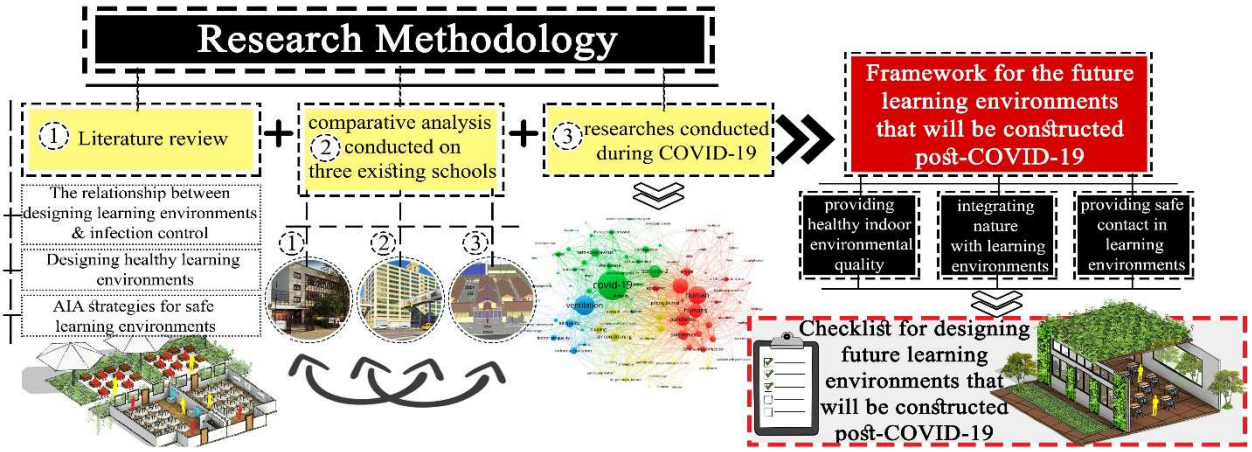

Fig. 2: Research methodology.

4 LITERATURE REVIEW

4.1 The relationship between designing learning environments and infection transmission control

Pandemics and intense catastrophes have always had a harmful impact on our built environment. In addition, they have transformed our built environment for many years. As a result, architects and urban planners acted as the treaters, helping stop pandemics by upgrading the design considerations of buildings throughout the years as a response to pandemics, as during pandemics, the form, like the function, has always followed the fear of infection (Ellin, 1999). As a consequence, the current health crisis demands upgrading the principles

of designing future schools to be healthy and resistant to any pandemic that can occur in the future (Megahed & Ghoneim, 2020). According to the hierarchy of hazard control, there are numerous strategies to maximize our defense against the infection transmission of COVID-19 or any virus, which can be concluded in five layers of defense as shown in Fig. 3. All layers must always be applied together to limit infection transmission, and the measure at the bottom of the hierarchy is more effective than those at the top. This hierarchy of hazard control shows that to limit infection transmission among students in schools, designing healthy learning environments will be an essential aspect in the future (CDC, 2015).

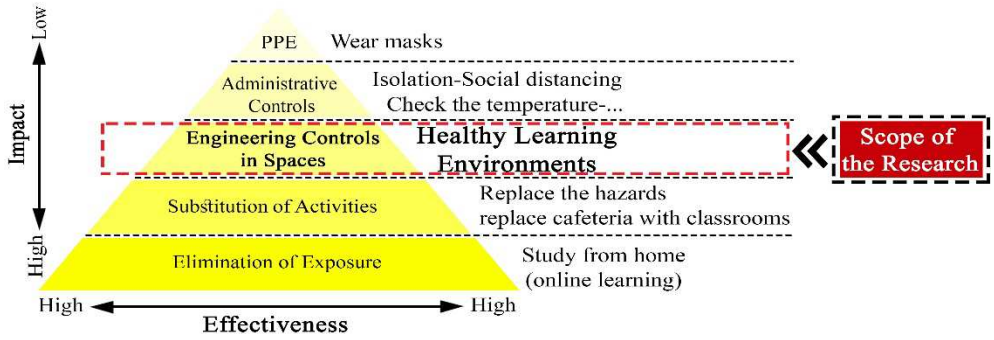

Fig. 3: Applying the hierarchy of controls in schools for COVID-19, upgraded from (CDC, 2015).

4.2 Designing healthy learning environments

According to Zhen et al., (2019), a "healthy building" is a physical structure that improves an individual's well-being and promotes healthy spaces as well as promoting physical, mental, and social health. Post-COVID-19 pandemic, healthy learning environments became a concept that must be applied to both future and existing schools to create ergonomic and healthy indoor learning environments (Megahed & Ghoneim, 2020; Saeed et al., 2021). This is because healthy learning environments can protect students from sickness and harm and promote preventative methods versus risk factors that might result in disease in the future by promoting suitable essential environmental factors (such as relative humidity, ventilation, thermal, acoustic, and lighting comfort, etc). It also can protect students from physical threats as well as protection from chemical and biochemical threats (WHO, 2004) as shown in Fig. 4.

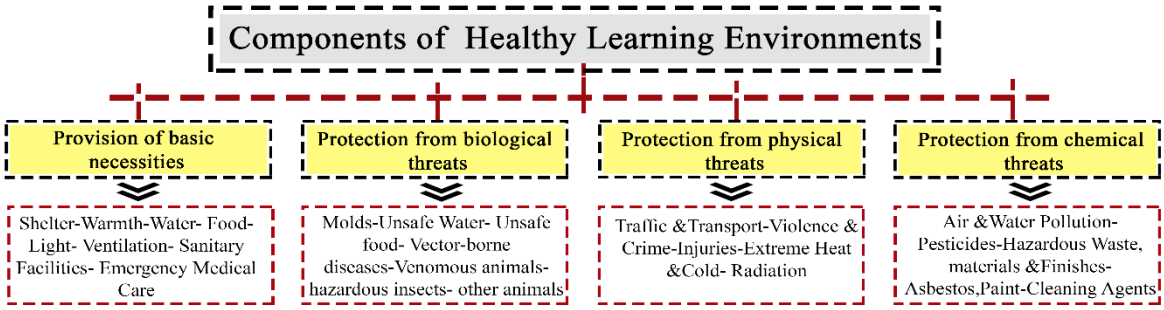

Fig. 4 : Components of healthy learning environments, upgraded from (WHO, 2004).

As previously mentioned, it will be crucial to design healthy learning environments in the future, not just to protect students from pandemics but also to protect them from any viruses or diseases that may harm their health. For instance, influenza is hazardous for young students due to their lack of immune systems, and this can harm their bodies to the extent of death (CDC, 2021). Healthy learning environments will enable students to learn and succeed in an atmosphere free from environmental risks or diseases, which will enhance their social, mental, and physical health (Saeed et al., 2021; WHO, 2004).

4.3 Strategies of AIA for the existing learning environments during the COVID-19 pandemic

For some students, the ability to attend physical classrooms can mean the difference between life and death, and there is no alternative to physical classrooms (OECD, 2020). Thus, AIA provided strategies focused on developing existing schools' designs in accordance with CDC and WHO guidelines to provide safe reopening for learning environments (AIA, 2020). The strategies of AIA for safe reopening schools can be concluded in three parameters: providing healthy indoor environmental quality, integrating nature with learning environments, and providing safe contact in the learning environments, as shown in Fig. 5.

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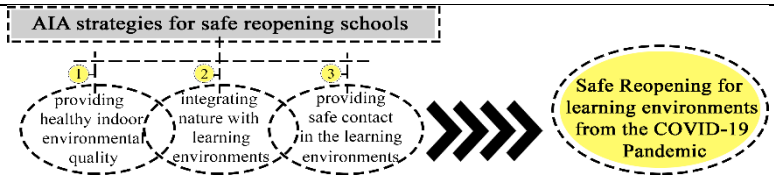

Fig. 5: AIA strategies for reopening schools safely.

4.3.1 Providing healthy indoor environmental quality

Indoor air quality (IAQ), thermal comfort, lighting and acoustic comfort are the four main indicators of indoor environmental quality. The quality of the indoor learning environment influences the built environment, affects students' health, and protects them from learning in a sick building syndrome (Megahed & Ghoneim, 2021). Fig. 6 shows The relationships between environmental health and its impact on health.

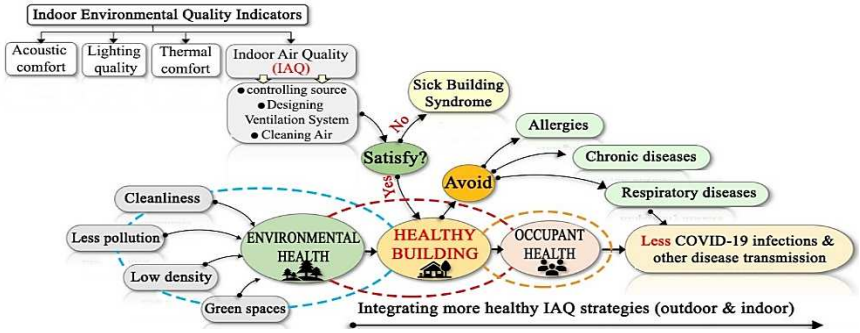

Fig. 6 : The relationships between environmental health and its impact on human health, (Megahed & Ghoneim, 2021).

The AIA has recommended the following strategies, as shown in Fig. 7, for ensuring indoor air quality:

- Relying on natural ventilation because it is very essential to control cross-infection by removing virus-laden aerosols exhaled by infected student by keeping windows and doors open, using ceiling exhausts to enhance the flow of air, and holding outdoor classrooms (CDC, 2019).
- Enhancing ventilation systems following ASHRAE recommendations, which include updated relative humidity (40–60 percent) and temperature (68–78 °F), as well as installing CO2 monitors, upgrading air filtration from MERV 8 to MERV 13 filters, and using UV light in HVAC and/or classrooms to purify the air from any pollutants and viruses(ASHRAE, 2023).

AIA recommended providing natural lighting whenever possible, Also AIA proposed using temporary shades to promote thermal comfort in outdoor spaces and outdoor classrooms during extreme weather; on the other hand, AIA suggested the use of microphones and speakers in the classrooms to provide acoustic comfort because masks can be considered as a sound barrier (AIA, 2020).

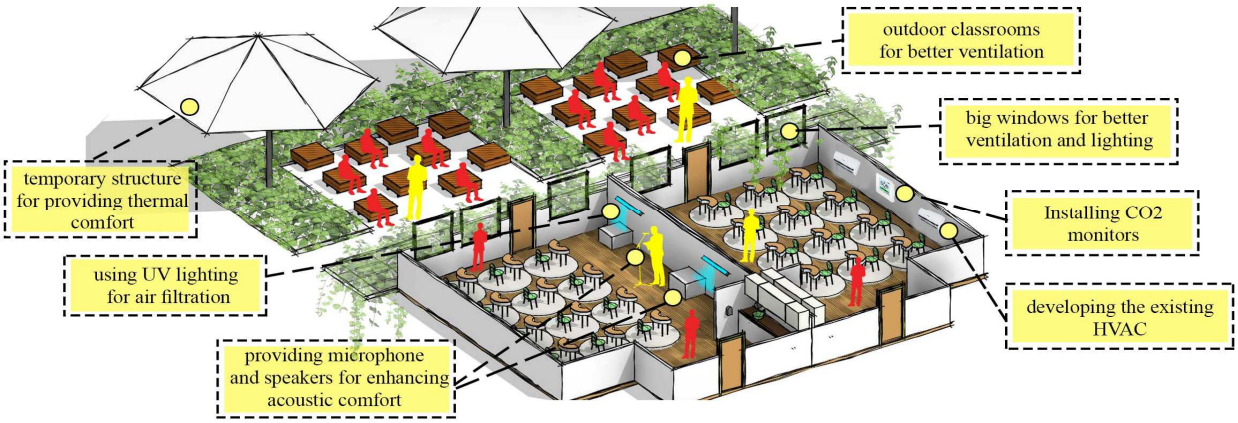

Fig. 7: AIA strategies for providing healthy indoor environmental quality in the learning environments.

4.3.2 Integrating nature with the learning environments

The COVID-19 pandemic has significantly changed learning environments, including increasing awareness that learning in outdoor areas can be safer than learning in indoor spaces when the infection is a a concern

(Jones et al., 2020). So AIA suggested holding classrooms and activities in outdoor spaces to promote natural ventilation and interactions between students and nature, as well as providing big windows and doors in each classroom to promote views to outdoor greenery and to provide access to outdoor spaces (AIA, 2020).

4.3.3 Providing safe contact in the learning environments

AIA proposed strategies that provide safe contact between students, which can be provided via hygienic control, using hygienic materials, providing touchless systems, and enhancing social distancing. AIA proposed measures to provide hygienic control by adding hygienic stations at schools' entrances, as shown in Fig. 8, as well as creating isolation rooms for infected students. AIA recommended using hygienic materials with short-term COVID-19 stability, such as copper and its alloy. As well as providing touchless systems by substituting flush valves and drinking water dispensers with touchless ones, controlling artificial lights and door openers is also recommended with touchless systems. AIA proposed several strategies to maintain social distancing between students in entrances, classrooms, circulation, and spatial organization. At entrances, social distancing was maintained by using ground markings indicating a minimum distance of 1.8 m between students. In addition to providing multiple points of entry, and applying staggered schedules to decrease traffic at entrances. In classrooms, AIA suggested keeping social distancing between students (with 1.8 m between each other) and, where social distancing is not feasible, placing transparent physical barriers. On the other hand, AIA promoted social distancing in circulation and spatial organization by creating one-way circulation in corridors and mapping the floors. Social distancing in schools caused a problem, which is that classroom areas are not large enough to accommodate all students at the same time while maintaining social distancing. Therefore, AIA proposed converting cafeterias and gyms into bigger classrooms and converting outside areas to outdoor classrooms and outdoor activities, also by using movable partitions. Another solution was providing distance and hybrid learning by providing classrooms with the essential tools, as shown in Fig. 9 (AIA, 2020).

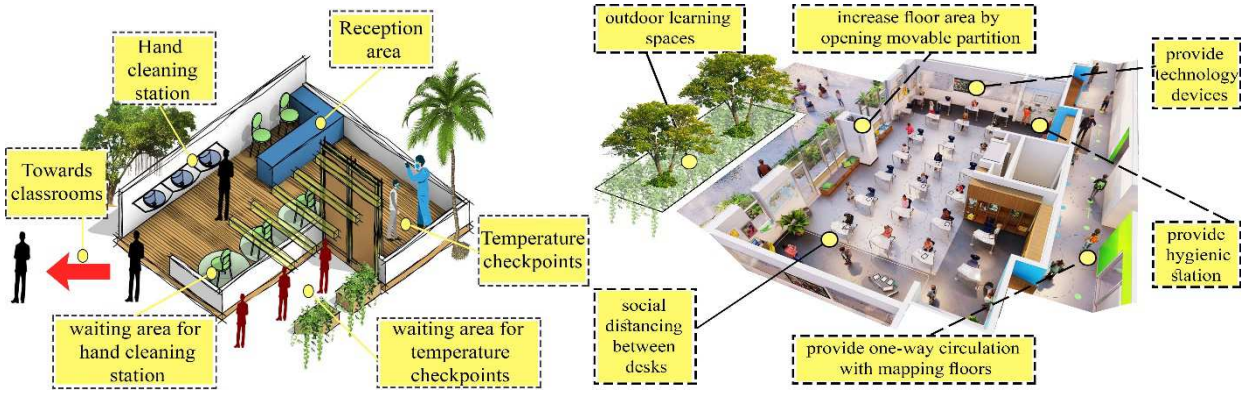

Fig. 8 (left) : Providing hygienic stations at schools' entrances. Fig. 9 (right) : AIA strategies for maintaining social distancing in classrooms, upgraded from (AIA, 2020).

5 COMPARATIVE ANALYSIS

This comparative analysis includes three examples of schools worldwide that have succeeded (if they were compared with other schools) to apply AIA strategies in their schools and transformed them into healthy learning environments during COVID-19 to limit infection. This comparative analysis is conducted according to AIA strategies between these examples, which are public school 138 Samuel Randall in the Bronx, Brooklyn Laboratory Charter Schools in New York, and Projeto Espaço Educativo 12 Salas – PEE-12 in Brazil. This comparative analysis aims to investigate the parameters and strategies of healthy learning environments that will be essential to make future learning environments resistant to any potential pandemic.

5.1 Public school 138 Samuel Randall in the Bronx, NY (elementary school)

The Urbahn architects designed a transforming proposal for this school to enable it to adapt to the COVID-19 pandemic. The Urbahn strategy focused on promoting hygienic control, so Urbahn suggested establishing two prefabricated handwashing stations before each entrance of the school, as shown in Fig. 10, as well as installing prefabricated wash stations in the hallways and each classroom to be accessible to all students, and also reusing auditoriums as isolation spaces. The Urban additionally concentrated on maintaining social distancing in entrances by adding entry points, providing social distancing in the sidewalk queue area (1.8m)

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by mapping the floor, and using transparent barriers between washbasins. They additionally maintained social distancing in classrooms by rearranging the furniture in a diagonal pattern to keep a distance of 1.8 meters between students. Besides using one-way circulation in stairways and pathways by using coloured tape on the flooring as shown in Fig. 11 and Fig. 12. (Dubey, 2020).

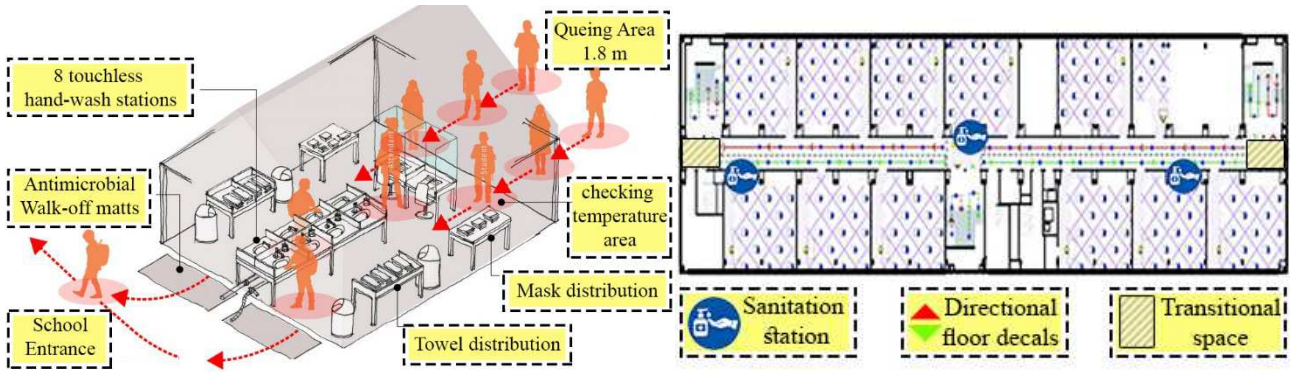

Fig. 10 (left) : Prefabricated handwashing stations before each entrance of the school, upgraded from (Dubey, 2020). Fig. 11 (right) :Social distancing in classrooms and paths, upgraded from (Dubey, 2020).

Because classroom sizes are insufficient to accommodate all the students with social distancing at once, one solution was to divide the cafeteria and gym into classrooms, as shown in Fig. 13. Other alternatives included offering an alternate schedule and encouraging hybrid learning to decrease densities. For long-term strategies, Urbahn architects proposed that future classrooms must be widened (AIA, 2020; Dubey, 2020).

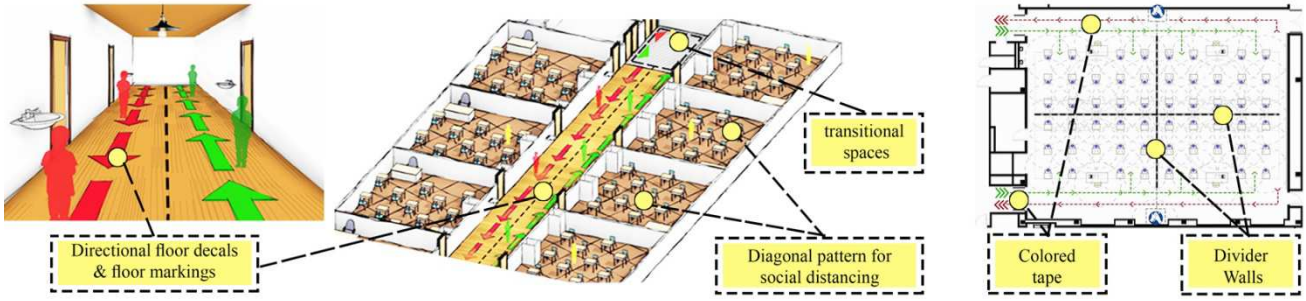

Fig. 12 (left) :Social distancing in classrooms and paths. Fig. 13 (right): Dividing gym into four classrooms by using divider walls , upgraded from (Dubey, 2020).

Furthermore, Urbahn suggested improvement of ventilation systems, particularly natural ventilation by using exhaust vents on the roof to speed up airflow and shutting return dampers to avoid air recirculation to decrease infection transmission. As well as utilizing MERV 14, 15, or 16 filters instead of MERV 13 filters and adding UV lamps and portable filtration devices in classrooms (ASHRAE, 2023; Dubey, 2020).

5.2 Brooklyn Laboratory Charter Schools in NY (middle and high school)

This school applied adaptation strategies to face COVID-19 pandemic, so the school collaborated with five design companies, including Gensler, PBDW, PSF Projects, SITU, and WXY, to come up with the best solutions, which were executed in the school. SITU designed a sidewalk with a shed at entrances, as shown in Fig. 14, for sanitizing hands and checking the temperature of students while maintaining social distancing (a minimum 1.8 m distance between students) by mapping the floor. They also proposed increasing entry points and using an alternative schedule. Whereas SITU and PSF suggested adding exterior stairs to the school as an additional vertical circulation to promote social distance, PBDW and Gensler concentrated on promoting social distance inside the classrooms (1.8 m) between students and/or utilizing a transparent barrier between students, as shown in Fig. 15. They additionally enhanced social distancing in circulation by providing one-way circulation in the paths and stairways by using coloured tape, as shown in Fig. 16. Because the classroom area is not big enough to accommodate all students while maintaining social distancing WXY suggested that sidewalks before entrances can be used as outdoor classrooms, as shown in Fig. 17, whereas PBDW proposed designing flexible classrooms with movable acoustic and whiteboard walls to promote extension, in addition to applying staggered schedules for online and hybrid learning.

Further, PBDW emphasized creating hygienic indoor learning environments by increasing airflow through window openings, upgrading HVAC air filters to MERV 13 filters, and keeping humidity levels 40%-60%

. Additionally, they provided touchless systems by adding foot controls for doors and sensor-operated hands-free technology for valves and flushometers in bathrooms (Brooklyn Lab Charter School, 2020).

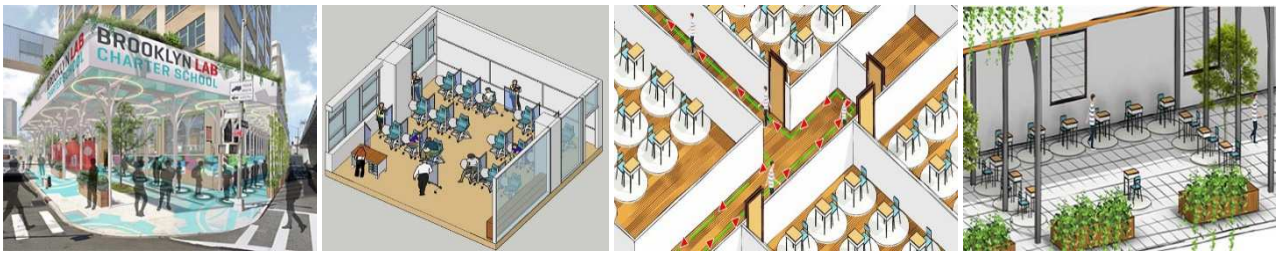

Fig. 14 (left): SITU design for the shed before entrance, (Brooklyn Lab Charter School, 2020). Fig. 15: Transparent barrier between students in classroom. Fig. 16: One-way circulation in the paths. Fig. 17(right): The proposed outdoor classrooms.

5.3 Projeto Espaço Educativo 12 Salas –PEE-12 in Brazil (elementary school)

During the COVID-19 pandemic, Furlani and Cardoso architects presented several adaptation solutions for the return to face-to-face classrooms in this standard public school in Brazil. They suggested strategies for hygienic control in schools, including providing sanitizer for the hands in all classrooms, using furniture made of cleanable material, and placing sanitary mats outside the school as shown in Fig. 18 (Fantini et al., 2020). They also recommended improving natural ventilation by providing cross ventilation which is more effective towards infection control than single-sided ventilation. Improving visual comfort was achieved by covering windows with shades to reduce glare, as shown in Fig. 19 (Furlani & Cardoso, 2021).

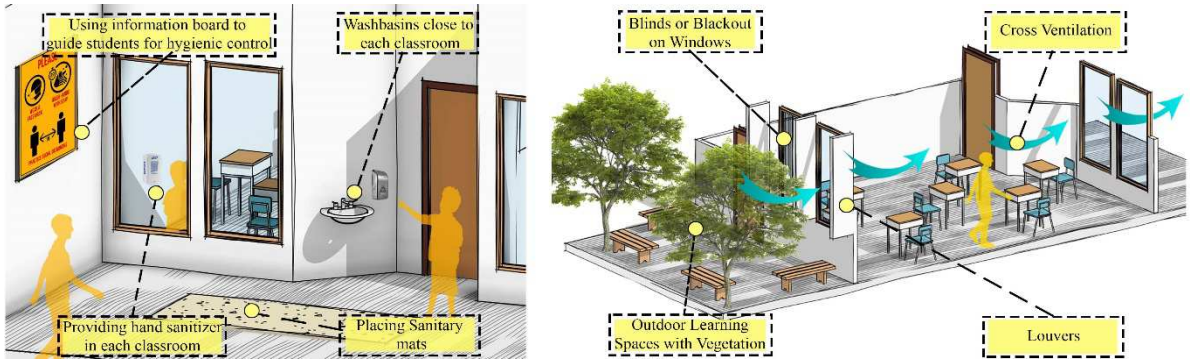

Fig. 18 (left): Hygienic control techniques in school. Fig. 19 (right):Techniques for better ventilation and lighting in classroom.

To connect students with nature, they encouraged creating areas in the outside yards that might serve as learning spaces and casual eating areas, as shown in Fig. 20 & Fig. 21. In order to maintain social distancing, they provided a polycentric layout in classrooms with a 2-metre space between student chairs, which can be movable as shown in Fig. 22. They also provided hybrid learning, so they supplied classrooms with technology devices like laptops, PCs, or tablets, projectors, printers, digital whiteboards, etc. Additionally, they provided alternative schedules to reduce traffic between students (Furlani & Cardoso, 2021).

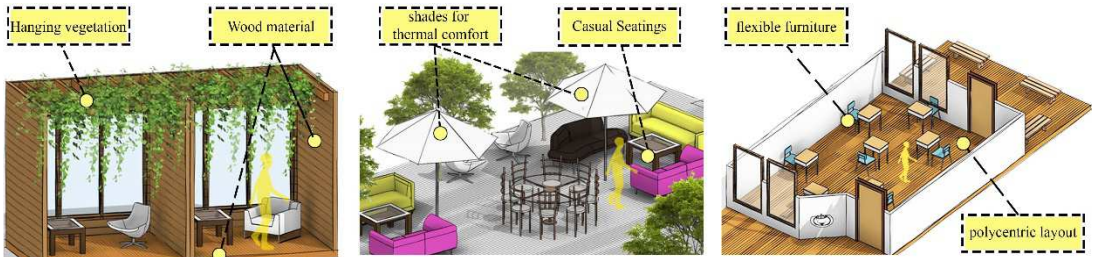

Fig. 20 (left): Outdoor learning spaces. Fig. 21 (middle): Outdoor casual eating area. Fig. 22 (right): Social distancing in classrooms.

6 DISCUSSION AND RESULTS

The comparative analysis reveals three main parameters of healthy learning environments, as shown in Table 1, that made these schools partially able to cope with COVID-19 as much as possible. On the other hand, these schools could not apply all strategies of the three parameters because they were restricted by many

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factors related to the existing schools' design, like site location and size, the condition of these schools, and the integration of the schools with surrounding areas. So applying strategies to existing schools will not fit or succeed completely in all the schools because of the restrictions in existing schools. On the other hand, these parameters and their strategies will be effective when considered in designing future learning environments.

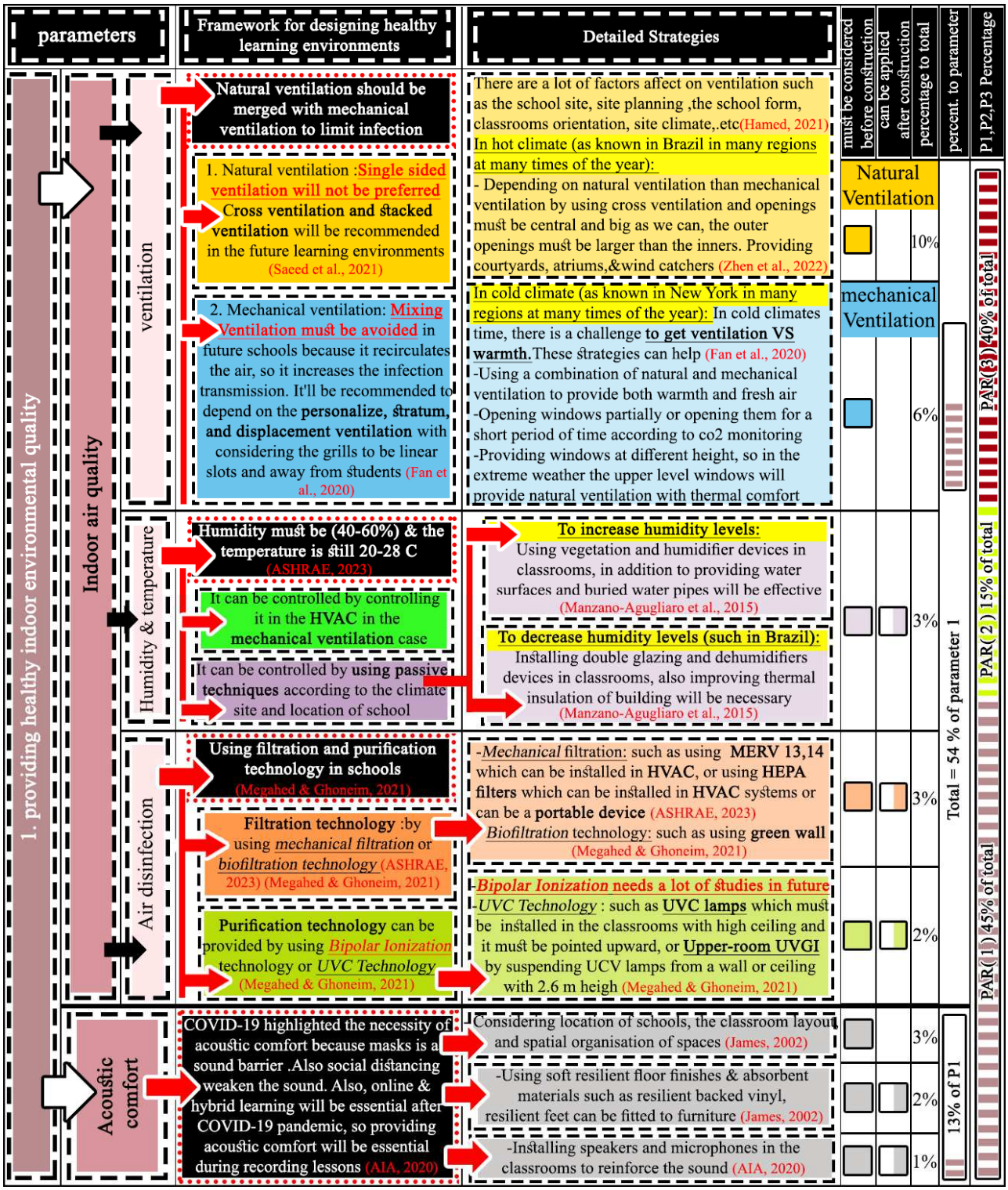
Parameters			public school 138 Samuel Randall in the Bronx	Brooklyn Laboratory Charter Schools in NY	Projeto Espaço Educativo 12 Salas – PEE-12 in Brazil
1.Providing healthy indoor environmental quality	Indoor Air Quality		- Promoting natural ventilation and using running exhaust vents on the roof -Using MERV 14, 15, or 16 filters and adding portable filtration units - Installing UV disinfection lamps -Closing return dampers	- Sanitizing ducts of HVAC - Keeping the humidity (40% - 60 %) -Opening windows to improve ventilation - Upgrading filters into MERV 13 filters -Providing outdoor classrooms and outdoor activity areas	-Promoting cross ventilation by opening the windows on the two sides. - Using the outside yards as outdoor classrooms and outdoor eating areas to increase natural airflow
	Acoustic comfort		.....	- Installing speakers on sidewalks that were as outdoor learning spaces	.....
	Lighting		.....	-Providing natural lighting in outdoor learning spaces by designing the shed with transparent material, also installing artificial lighting to the sidewalk areas	- Using blinds and louvers on windows to avoid glare in classrooms -Providing artificial lighting in outdoor spaces
	Thermal comfort		.....	- Designing outdoor sheds at sidewalks areas & outdoor learning spaces	-providing shades for outdoor space - using louvers on classrooms facade
2. Integrating nature with the learning environments			.....	-Providing terraces and outdoor spaces to encourage outdoor learning & activities - Using vegetation elements in outdoor areas and terraces.	- Designing classrooms with big windows to provide views to outdoor green areas - Using outdoor areas as learning spaces - Using natural materials such as wood
3. Providing Safe contact in the learning environments	Hygienic Control		- Installing two prefabricated hygienic stations at each entrance - Adding prefabricated wash stations in the hallways and in each classroom - Reusing auditoriums to be isolation rooms	- Creating sidewalk sheds before entrances to be hygienic stations and to check temperature of students before entering schools -Setting up hygienic stations in each classroom.	-Installing information signages to guide students to avoid sharing items and wear masks - Putting washbasins near each classroom, and providing sanitizers in other spaces
	Hygienic Materials		- Adding antimicrobial walk-off mats before school entry	.....	-Replacing coatings that are difficult to maintain and clean, in addition to using furniture made of cleanable material - Placing sanitary mats outside the school
	Touchless Systems		- Installing sensor control faucets and liquid soap dispensers in hygienic stations	- Adding foot controls for doors, and sensor-operated hands-free technology for valves and flushometers in bathrooms	.....
	Providing Social Distancing	In physical learning environments	entrances		
			- Adding additional entry points in addition to maintaining social distancing in the sidewalk queuing area (1.8m) by mapping the floor	- Increasing entry points - Using an alternative schedule - Adding exterior stairs to the school as an additional vertical circulation	.....
			classrooms		
			- Rearranging the furniture in a diagonal pattern to keep a distance of 1.8 meters between students - Dividing the cafeteria and gym with divider walls to be smaller classrooms -Providing an alternative schedule - In the long-term strategies, classrooms must be bigger in the future	-Promoting social distance (1.8 m) between students by mapping floors - Utilizing a transparent barrier - Holding outdoor classrooms to reduce the density of students - Applying staggered schedules - Designing flexible classrooms with movable walls to promote the extension	- Providing a polycentric layout in classrooms with a 2-meter space between student chairs which can be movable - Using an alternative schedule - Repurposing the outside yards into spaces for informal eating and classrooms
			circulation&spatial organization		
			-Using one-way circulation in stairways and pathways by using colored tape on the flooring to define circulation patterns	-Providing one-way circulation in the paths and stairways by using colored tape on the floors	.....
		In online learning	- Promoting hybrid & Online learning	- Providing hybrid & Online learning	-Providing hybrid learning by supplying classrooms with technology devices like laptops, PCs, tablets, projectors, etc.

Table 1: Comparative analysis between the three examples.

7 FRAMEWORK FOR FUTURE HEALTHY LEARNING ENVIRONMENTS

According to AIA strategies, comparative analysis, and a lot of studies that have been recently done in light of the COVID-19 pandemic, a framework has been reached for designing future learning environments. This framework is generic and does not relate to specific countries (considering Brazil & New York) and provides a lot of detailed strategies to achieve the same parameters, while each future school can apply the appropriate strategies from the framework according to its factors like school location, climate, cost, etc. So the framework isn't prescriptive for schools, but it defines the priorities of strategies according to their importance to make schools healthy. On the other hand, it's very hard to apply this framework to existing schools because of their restrictions, like site planning, existing building conditions, etc. While it will be effective when applied to future schools. The framework provides three parameters that must be promoted in future learning environments: providing healthy indoor environmental quality, integrating nature with the learning environments, and providing safe contact in the learning environments (Table.2). The framework provides a scoring system; Each parameter gets a different percentage according to its importance to make the school healthy and able to cope with pandemics based on the literature review and the WELL rating system for healthy buildings. Each parameter can be prompted by a lot of strategies that have a percentage to achieve the main parameter. Parameter 1 strategies make schools healthy with 45%, Parameter 2 strategies

make schools healthy with 15%, and Parameter 3 strategies make schools healthy with 40%. The framework will help architects to identify (before construction) if the future school will be able to face pandemics or not by giving it a percentage for each strategy of the proposed design. If the percentage of the school is less than 50%, then additional strategies from the framework can be added to make schools resistant to pandemics.



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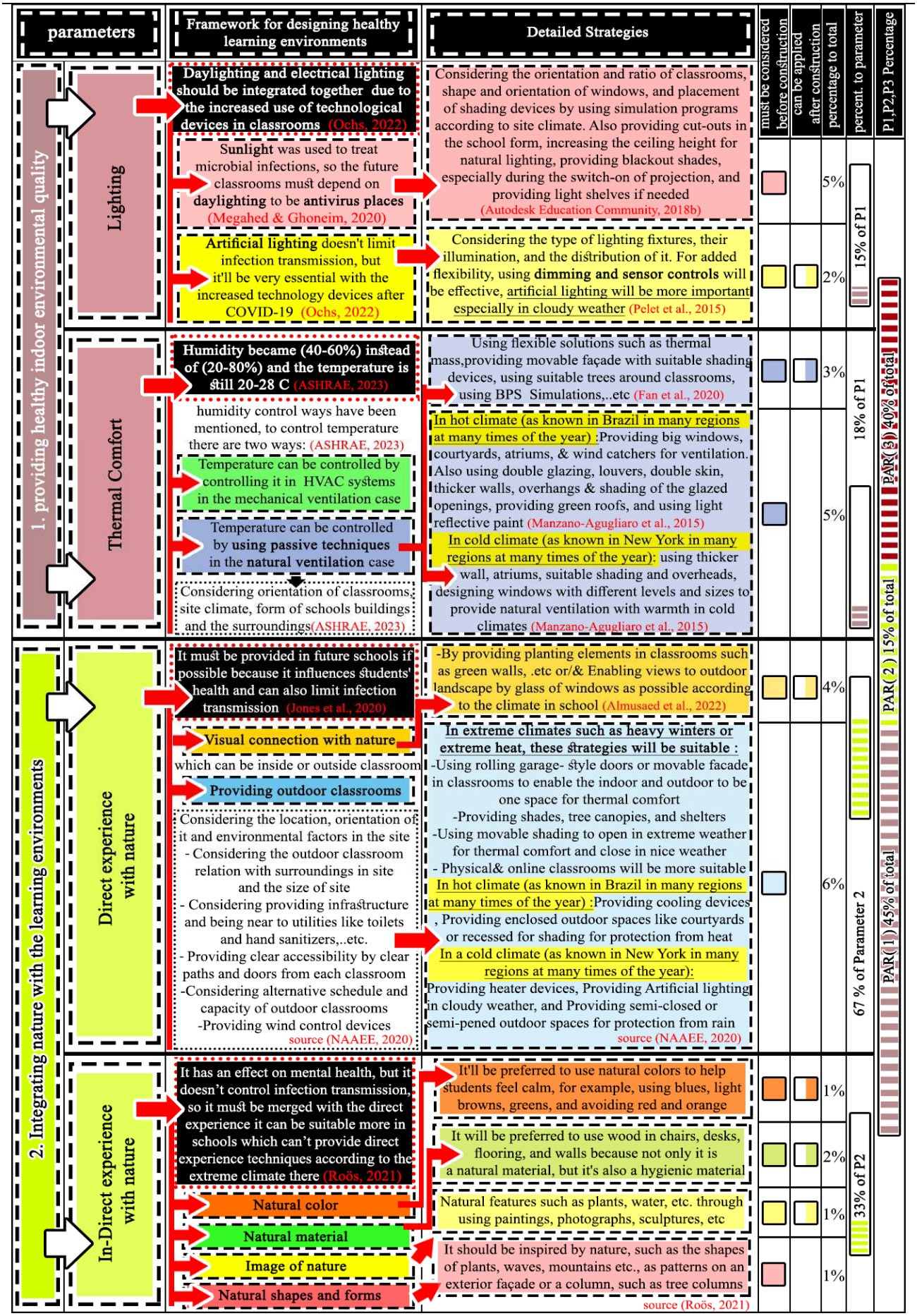
parameters
Framework for designing healthy learning environments
Detailed Strategies
must be considered before construction
can be applied after construction
percentage to total
percent. to parameter
P1,P2,P3 Percentage
1. providing healthy indoor environmental quality
Lighting
Daylighting and electrical lighting should be integrated together due to the increased use of technological devices in classrooms (Ochs, 2022)
Sunlight was used to treat microbial infections, so the future classrooms must depend on daylighting to be antivirus places (Megahed & Ghoneim, 2020)
Considering the orientation and ratio of classrooms, shape and orientation of windows, and placement of shading devices by using simulation programs according to site climate. Also providing cut-outs in the school form, increasing the ceiling height for natural lighting, providing blackout shades, especially during the switch-on of projection, and providing light shelves if needed (Autodesk Education Community, 2018b)
5%
Artificial lighting doesn't limit infection transmission, but it'll be very essential with the increased technology devices after COVID-19 (Ochs, 2022)
Considering the type of lighting fixtures, their illumination, and the distribution of it. For added flexibility, using dimming and sensor controls will be effective, artificial lighting will be more important especially in cloudy weather (Pelet et al., 2015)
2%
15% of P1
Thermal Comfort
Humidity became (40-60%) instead of (20-80%) and the temperature is still 20-28 C (ASHRAE, 2023)
Using flexible solutions such as thermal mass,providing movable façade with suitable shading devices, using suitable trees around classrooms, using BPS Simulations,..etc (Fan et al., 2020)
3%
humidity control ways have been mentioned, to control temperature there are two ways: (ASHRAE, 2023)
Temperature can be controlled by controlling it in HVAC systems in the mechanical ventilation case
Temperature can be controlled by using passive techniques in the natural ventilation case
In hot climate (as known in Brazil in many regions at many times of the year) :Providing big windows, courtyards, atriums, & wind catchers for ventilation. Also using double glazing, louvers, double skin, thicker walls, overhangs & shading of the glazed openings, providing green roofs, and using light reflective paint (Manzano-Agugliaro et al., 2015)
In cold climate (as known in New York in many regions at many times of the year): using thicker wall, atriums, suitable shading and overheads, designing windows with different levels and sizes to provide natural ventilation with warmth in cold climates (Manzano-Agugliaro et al., 2015)
5%
18% of P1
Considering orientation of classrooms, site climate, form of schools buildings and the surroundings(ASHRAE, 2023)
PAR(3) 40% of total
2. Integrating nature with the learning environments
Direct experience with nature
It must be provided in future schools if possible because it influences students' health and can also limit infection transmission (Jones et al., 2020)
-By providing planting elements in classrooms such as green walls, .etc or/& Enabling views to outdoor landscape by glass of windows as possible according to the climate in school (Almusaed et al., 2022)
4%
Visual connection with nature
which can be inside or outside classroom
Providing outdoor classrooms
In extreme climates such as heavy winters or extreme heat, these strategies will be suitable :
-Using rolling garage- style doors or movable facade in classrooms to enable the indoor and outdoor to be one space for thermal comfort
-Providing shades, tree canopies, and shelters
-Using movable shading to open in extreme weather for thermal comfort and close in nice weather
- Physical& online classrooms will be more suitable
In hot climate (as known in Brazil in many regions at many times of the year) :Providing cooling devices , Providing enclosed outdoor spaces like courtyards or recessed for shading for protection from heat
In a cold climate (as known in New York in many regions at many times of the year):
Providing heater devices, Providing Artificial lighting in cloudy weather, and Providing semi-closed or semi-pened outdoor spaces for protection from rain
source (NAAEE, 2020)
6%
67 % of Parameter 2
Considering the location, orientation of it and environmental factors in the site
- Considering the outdoor classroom relation with surroundings in site and the size of site
- Considering providing infrastructure and being near to utilities like toilets and hand sanitizers,..etc.
- Providing clear accessibility by clear paths and doors from each classroom
-Considering alternative schedule and capacity of outdoor classrooms
-Providing wind control devices
source (NAAEE, 2020)
PAR(2) 15% of total
PAR(1) 45% of total
In-Direct experience with nature
It has an effect on mental health, but it doesn't control infection transmission, so it must be merged with the direct experience it can be suitable more in schools which can't provide direct experience techniques according to the extreme climate there (Roös, 2021)
It'll be preferred to use natural colors to help students feel calm, for example, using blues, light browns, greens, and avoiding red and orange
1%
Natural color
It will be preferred to use wood in chairs, desks, flooring, and walls because not only it is a natural material, but it's also a hygienic material
2%
Natural material
Natural features such as plants, water, etc. through using paintings, photographs, sculptures, etc
1%
33% of P2
Image of nature
It should be inspired by nature, such as the shapes of plants, waves, mountains etc., as patterns on an exterior façade or a column, such as tree columns
source (Roös, 2021)
1%
Natural shapes and forms

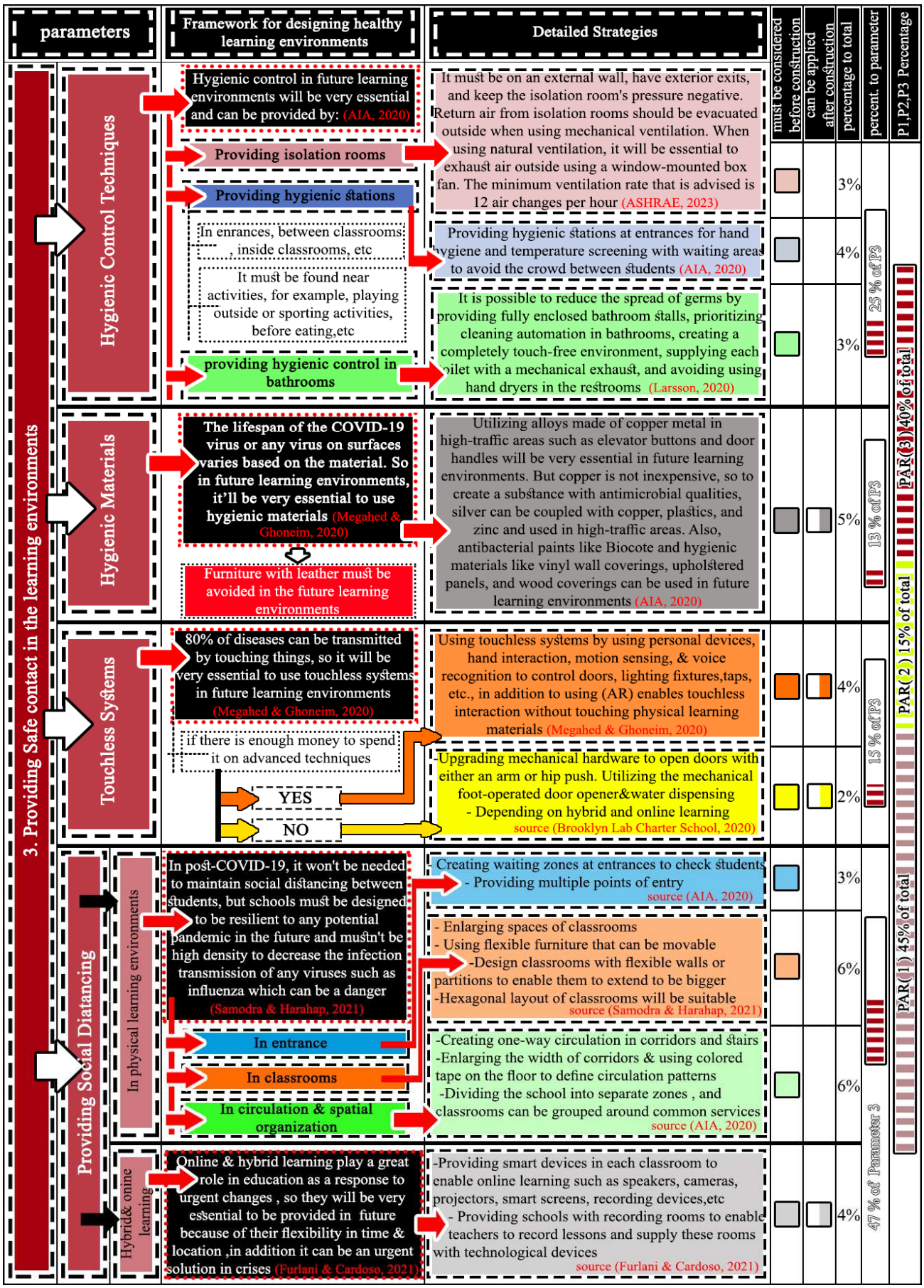

Table 2: Framework for designing future learning environments.

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8 CHECKLIST FOR DESIGNING FUTURE LEARNING ENVIRONMENTS THAT WILL BE CONSTRUCTED POST COVID-19

Table 3 provides checklist for designing future learning environments to make them resistant to pandemics.

Classrooms	
☐Installing signs for prevention measures. ☐Mapping floors to delineate one-way walking paths and furniture locations.	☐Providing classrooms with technological devices such as laptops, projectors, cameras, speakers, etc. for hybrid and online learning.
☐Designing classrooms with flexible walls or partitions. ☐Using movable furniture.	☐Creating touchless handwashing hygiene stations in or adjacent to the classroom or sanitizing station(s).
☐Considering the finishing materials to be a hygienic material like antibacterial paint, wooden and vinyl coverings, nanomaterial, etc.	☐hexagon layout of the classroom If it's possible, this shape will be suitable based on the shape of the virus head biologically.
	☐Expanding the size of classrooms than in current schools.
Acoustic comfort	
☐Considering being away from sources of noise such as mechanical rooms, etc. ☐Considering the layout and geometry of the classroom, and avoid using domes or barrel vaults in the classroom section, also avoid using a curved wall in opposition to a flat wall. ☐Enhancing acoustic treatment in classrooms by using absorbent materials if it's needed. ☐Installing microphones and speakers.	☐Using touchless systems to open doors and windows as much as possible, if it isn't possible, using mechanical push by arm or foot to open them, or if it isn't possible, using copper in door and window handles and elevator buttons will be effective.
	Engaging classrooms with nature
	☐providing planting elements in classrooms. ☐Using natural and organic shapes in furniture if it's impossible according to learning styles. ☐Providing natural features and natural colors. ☐Using natural materials that can be antibacterial ☐Enabling views to outdoor landscape through as many windows as possible according to the climate in school. ☐ Each classroom should have a door for entry and another for accessibility to outdoor classrooms if the climate is suitable for outdoor classrooms, as we will mention in the checklist.
Providing suitable ventilation	
☐ Considering the site climate, location of classroom, and the wing walls placement by using simulation programs. ☐Installing CO2 monitoring. ☐ Considering the form of the school, the height of the classrooms, and the roof shape of them. ☐Considering the orientation of the classroom according to the climate and the style of learning, it's generally recommended to have a northern orientation. ☐ **Providing windows at different heights, so in extreme weather, the upper-level windows will provide natural ventilation with thermal comfort.** ☐Using suitable mechanical ventilation like POV, Stratum, PEV, Displacement ventilation, Mixing ventilation must be avoided. In hot climate, for example (**as known in Brazil in many regions at many times of the year**): ☐Using cross ventilation. Openings must be as central and big as possible .The outer openings must be larger than the inners. ☐Providing courtyards, atriums, & wind catchers ☐Using single sided ventilation with improving by splitting the opening into two by using wings wall , using fans, and providing transom window above the door if the cross ventilation is impossible to be achieved. In cold climate, for example (**as known in New York in many regions at many times of the year**): ☐Using a combination of natural and mechanical ventilation to provide both warmth and fresh air. ☐One way is to partially open windows or to open them for a short period of time, according to CO2 monitoring. ☐ Opening higher-up windows during heavy rain.	Providing thermal comfort (20-28 C) & (40-60%) humidity
	☐ Considering the orientation of classrooms & site climate. ☐Using movable façade with suitable louvers ☐Using suitable trees and considering thermal mass ☐Using Building Performance Simulations (BPS) ☐Using suitable HVAC systems In hot climate, for example (**as known in Brazil in many regions at many times of the year**): ☐Providing big windows, courtyards, atriums, and wind catchers for providing cross ventilation. ☐ Using double glazing, louvers, double skin, thicker walls, overhangs, and shading of the glazed openings. ☐ Providing green roofs and light reflective paint. ☐ The humidity in Brazil is more than 60%,, so using a dehumidifier in classrooms will be effective. In cold climate, for example (**as known in New York in many regions at many times of the year**): ☐ Using thicker walls, atriums, and suitable shading ☐ Designing windows with different levels and sizes to provide natural ventilation with warmth in cold climates.
	Lighting comfort
	☐Considering the orientation and the classroom ratio, also the shape and orientation of windows and shading device placement by using simulation programs ☐ Providing cut-outs in the school form if it is possible. ☐Providing blackout shades, especially during projection. ☐Increasing the ceiling height for natural lighting. ☐Considering artificial lighting using sensors
Using filtration and purification technology in classrooms	
☐Using green walls or planting filters. ☐Installing UVC lamps or UVGI at high levels. ☐Using MERV 13,14 or/ and HEBA.	

outdoor classrooms	Site

☐Considering the location of it to be in quiet spaces, well connected to classrooms to enable teachers to monitor students, and not in dark or corner places for student safety. ☐ Considering the climate in the schools and whether it's possible to provide outdoor classrooms or not in schools. ☐ Considering outdoor classrooms orientation and relation of them with the surroundings on site and the site size. ☐ Considering providing infrastructure and being near utilities like toilets and hand sanitizer. ☐Providing Clear accessibility by providing clear paths and doors from each classroom and making them well defined. ☐Providing wind control devices in outdoor classrooms. ☐Designing them with buffer space around them for movement. ☐Considering the alternative schedule and capacity of it. ☐Considering designing soft and hard landscape elements.	☐Considering the location of the school's site to be away from noisy. ☐Providing multiple points for entry and exits. ☐Having enough space before each entrance to have a waiting area before the entrance for checking the temperature of students and providing hygienic stations. ☐Considering the site size and site planning to enable it to extend to future needs and to provide outdoor classrooms, playgrounds, and classrooms in suitable spaces. ☐Considering providing separate parking circulation away from students. ☐Considering staggered times for entry if it is needed. ☐Considering spacing buildings' schools by a distance of at least 5 times the height of schools to provide natural ventilation ☐Considering the placement and types of vegetation and trees on the site.
In extreme climates, such as heavy winters or extreme heat	
☐**physical and online classrooms will be more suitable** ☐Using rolling garage- style doors or movable facade in classrooms to enable the indoor and outdoor spaces to be one space for thermal comfort. ☐Using movable shading to open in extreme weather for thermal comfort and close in nice weather. In hot climate, for example (**as known in Brazil in many regions at many times of the year**): ☐Providing cooling devices in hot regions. ☐considering drainage and protection from landslides. ☐Providing enclosed outdoor spaces like courtyards or recessed for shading for protection from heat. In cold climate, for example (**as known in New York in many regions at many times of the year**): ☐Providing heater devices in cold regions. ☐Providing Artificial lighting in cloudy weather. ☐Providing semi-closed or semi-open outdoor spaces for protection from rain.	Services and additional spaces
	General notes
	☐Using touchless systems to open doors and windows as much as possible, if it isn't possible, providing mechanical push by arm or foot to open them, or if it isn't possible, using copper in door and window handles will be effective. ☐Considering the finishing material to be hygienic material like using antibacterial paint, nano coating materials, etc. ☐Using touch-free faucets, sinks, soap dispensers,etc. ☐Mapping the floor of the cafeteria, gym, and other service spaces to define the circulation path as one-way.
	New additional spaces should be considered in schools
	☐Providing isolation rooms for infected students with negative pressure, separated entry and exit, and a separate toilet. Also, it should be located on an exterior wall. ☐Providing recording rooms with technological devices for recording lessons in hybrid and online learning.
	Bathrooms
	☐Providing toilets with side exhaust fans. ☐providing enclosed bathroom stalls. ☐Cleaning automation in bathrooms will now be a priority. ☐Using cleaning robots and self-cleaning devices with touch-free faucets, sinks, soap dispensers,etc.
Circulation and Spatial organizations	
☐Breaking down the school into separate zones, and classrooms can be grouped around common services. ☐Avoiding pinch points. ☐Providing one-way circulation in corridors and stairs. ☐Mapping the floor to define the circulation paths. ☐Eexpanding the width of corridors than in current schools. ☐Providing single-loaded corridors if possible for ventilation if it'll be suitable according to the climate. ☐Considering cutouts in a building's form by classroom organization for daylighting if it will be suitable with climate.	Cafeteria, gym, and other services spaces
	☐Considering acoustics, lighting, thermal comfort, ventilation, air filtration, and engaging spaces with nature as mentioned in the checklist of classrooms. ☐Installing signs for prevention measures. ☐Providing entry and exit for the large service spaces. ☐Providing hygienic stations in each space. ☐Using flexible furniture in cafeterias, gyms, etc.

Table 3: Checklist for designing future learning environments, Author based on the previous framework sources.

9 CONCLUSION

COVID-19 has highlighted the lack of health in our learning environments, so the parameters for designing learning environments must be updated in the future to provide healthy learning environments. The parameters that must be provided in future learning environments to make them able to face any pandemic or crisis are: providing healthy indoor environmental quality (by promoting indoor air quality, acoustic, lighting, and thermal comfort); integrating nature with the learning environments (by providing natural views, outdoor classrooms, etc.); and providing safe contact in the learning environments(by providing hygienic stations, hygienic materials, touchless systems, and making the learning environment flexible to extend or be able to maintain social distancing in case there is any pandemic).

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