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Resilient Schools Amid Epidemics: Multifunctional Design Strategies

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ABSTRACT

This research aims to propose an epidemic-resilient school design through multifunctional space technique, as a promising solution that allows to guarantee social distancing, manages the circulation of students within classrooms, optimizes spaces and prevents significant disadvantages in terms of effectiveness, inclusion and flexibility. Furthermore; it allows to create more flexible, safe and efficient school environments, even in normal situations. The crucial role of a multifunctional space and its relevance in epidemic situations and normal conditions is highlighted and compared with alternative options such as movable or collapsible partitions. Multifunctional space has been shown to be advantageous in emergency management, allowing active reorganization of space without requiring outside intervention. The design of multipurpose spaces emerges as an effective and sustainable strategy to ensure safety and continuity in education. Investment in proactive design solutions proves crucial to foster continuous learning that is safe and adaptable to the changing needs of the educational environment.

1. INTRODUCTION

COVID-19 pandemic has posed new challenges to the school system, requiring flexible and safe solutions to ensure the continuity of face-to-face teaching activities, even in health emergency situations; it is a more efficient solution than alternative teaching methods, such as online or shift teaching. The COVID-19 pandemic has had profound implications on the mental health of children and adolescents, a reality that has been widely documented through a variety of research studies. Infection control strategies, such as the closure of educational institutions, the adoption of social distancing, and generalized restrictions, have undoubtedly had a detrimental impact on the well-being of students. A telling example comes from a study conducted by the Regional Documentation Center for Health Promotion, both nationally and internationally, which investigated the effects of the COVID-19 pandemic on the mental health of young people. In the city of Wuhan, the epicenter of the epidemic in China, there was a significant increase in depressive symptoms (22%) and anxiety (18.9%) among elementary and middle school students in the first four months of the year. These significant percentages were attributed to the lack of school attendance, restrictions on outdoor activities, and the limitation of social interactions with peers, highlighting in an undeniable way the negative impact of a health emergency [1].

Realizing the ominous consequences on this age group, several European countries opted to reopen schools in October 2020, even though the pandemic persisted. The Irish prime minister, reflecting on this decision, stated, “We do not want the future of our children and youth to be another victim of this pandemic” [2], “Effetti della Pandemia di COVID-19 Sulla salute mentale dei Bambini e degli Adolescenti”, This determination was based on awareness of the possible long-term negative consequences of prolonged closure of educational institutions [3].

The European map, circulated by the Italian agency “AGI,” documenting the status of school opening and closing in various European countries, reflects the diversity of approaches taken in relation to the evolving epidemiological situation and the progress of the epidemic. The reopening of schools was accompanied by precise rules in accordance with current health regulations, which included social distancing, the obligation to wear a mask, class isolation and the administration of the PCR test to all classmates in case of positivity [4].

Data from a study conducted at Duke University, which involved collaboration with more than 50 school districts and local health departments, indicated that incidents of infection within schools were less widespread than initially feared. For example, in North Carolina, out of 197 recorded cases of infection, only eight transmissions occurred within school facilities [5]. Similarly, the National Institute of Health concluded that schools, taking established precautions such as the use of masks, hand washing, and adequate ventilation, constituted relatively safe environments with a limited contribution to coronavirus transmission in Europe [6].

UNICEF has sounded the alarm regarding approximately 168 million children worldwide who have experienced complete school closures due to COVID-19-related quarantine measures, also highlighting the 214 million children who have missed more than 75 percent of school attendance [7]. As such, the need for relentless efforts to keep schools open and give them the highest priority in reopening plans, avoiding further years of limited or absent learning for these children, clearly emerges. Thus, there is a clear perspective that schools should be the last institutions to close during epidemics.

However, successfully achieving this goal requires a collective effort by the global community to identify safe solutions that enable schools to operate safely even in the presence of epidemics. Architects play a critically important role in this context, contributing answers and solutions through appropriate and safe planning for the operation of schools, both during and after epidemics. Their growing relevance emerges from being considered key figures in shaping the future of cities and in post-COVID urban development and planning [8].

The design of educational institutions geared toward effective functionality in epidemic settings is based on a diverse body of research findings, spanning several disciplines, including psychology. This principle is clearly evident in studies conducted, as exemplified in the article [9].

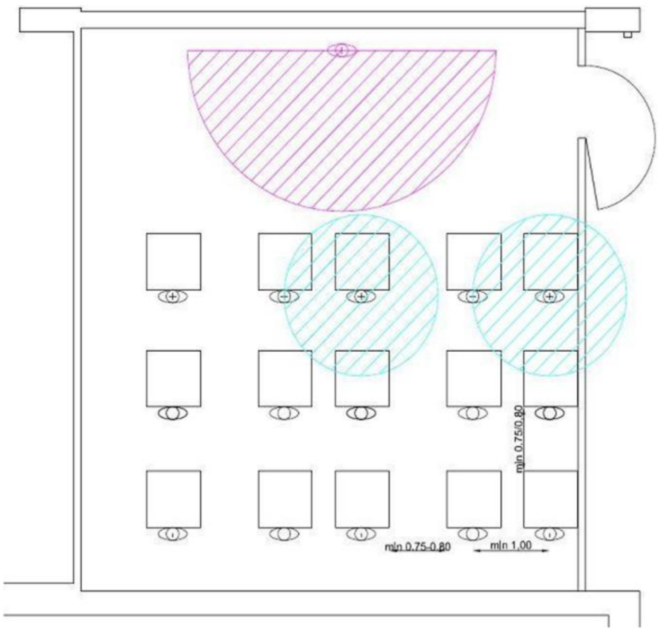

Figure 1. Schema of the arrangement of desks presenting the safe space between students, currently valid in Italy (the measurements are expressed in meters [10]

A tangible example of this thorough design is manifested in the scheme proposed by the Scientific Technical Committee (STC) of the Italian Ministry of Health. This scheme (Figure 1) details the minimum distances to be maintained in classroom corridors, thus contributing to a structure that promotes social distancing [11]. A second example (Figure 2), offers a glimpse into the internal organization of spaces, with desks arranged in a horseshoe shape to ensure a distance of at least two meters between each student. In addition, it is essential to emphasize the strategic importance of adequate lighting and efficient natural ventilation, pivotal elements in reducing the spread of viruses and bacteria within the school environment (Figure 3). The latter schematic representation highlights the flow and movement of students, clearly delineating how they move from arrival areas to different school activities according to the diagram [12].

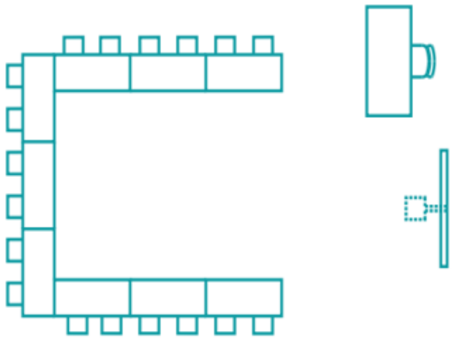

Figure 2. Internal organization of spaces, with desks arranged in a horseshoe shape [13]

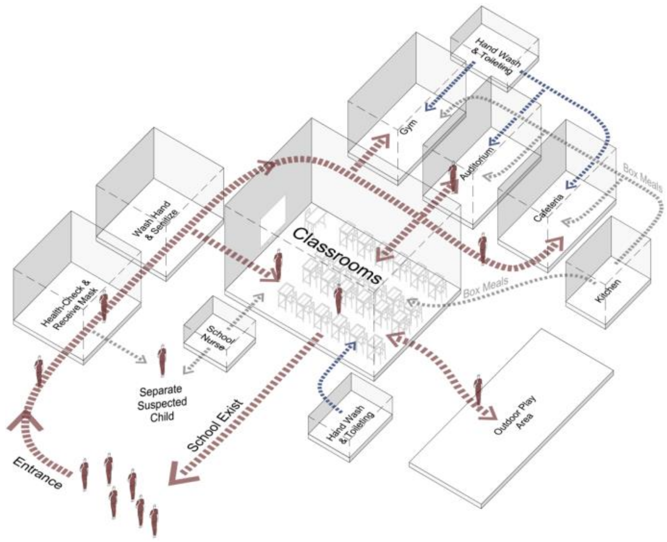

Figure 3. Implementing strategic student pathways and utilizing large spaces to minimize contagion risk in schools

2. EPIDEMIC RESILIENT DESIGN: PROPOSED STRATEGY AND METHODOLOGY

This research aims to outline an approach to the design of epidemic resilient educational institutions. This will not only constitute a crucial case study but also serve as a fundamental reference for architects and scholars. Its relevance emerges considering the increased likelihood of future outbreaks of epidemics, which are often desensitized by new pathogens [14, 15]. Consequently, it is imperative that experts in the field promptly address the pressing issue of designing schools capable of effectively managing such epidemic contexts in their spaces.

The design of public buildings requires the implementation of control mechanisms aimed at preventing disease transmission, considering the potential risk of infection within such facilities. Our strategy for schools, especially in epidemic situations, goes beyond the mere implementation of control mechanisms. It focuses on a detailed analysis of the flexibility of classroom size and user circulation, leading to the development of unidirectional pathways during times of high student influx within the school, thus ensuring that the necessary social distances are respected.

In addition, it is crucial to ensure proper natural ventilation and lighting in spaces and corridors intended for the movement or temporary stay of people. Recent research has shown that adequate natural ventilation can contribute significantly to reducing the risk of infection within healthcare and public facilities [16, 17]. As an example, a study conducted in isolation units in Chinese hospitals with significant openings to the outdoors has shown remarkable success in preventing the spread of SARS among healthcare personnel [18].

To ensure the well-being of occupants, it is essential to comply with the parameters set by law for microclimate conditions in school workplaces, such as classrooms. These parameters include air humidity (40%-50% in winter, 50%-60% in summer), fresh air flow (at least 25 m^3/hour per occupant), air temperature (19℃-22℃ in winter, 24℃-26℃ in summer) and air velocity (minimum of 0.05 m/s, maximum of 0.15 m/s in winter, 0.25 m/s in summer). In addition, in the aftermath of the COVID-19 emergency, consideration is being given to improving the air filtration system, especially where mechanical ventilation systems are in use, and to maintaining constant air quality supervision [19].

Another crucial element is the presence of natural light in school environments, which contributes to the users' physical health and psychological well-being. Such lighting positively influences circadian rhythm, concentration, cognitive development and learning efficiency. Spaces with adequate levels of natural lighting and balanced distribution also allow for flexibility in adapting and rearranging spaces, if necessary, without significantly impacting performance [19-21].

2.1 Designing multipurpose epidemic resilient spaces

The design of spaces that can effectively adapt to the needs of epidemic situations plays a key role in ensuring the continuity of in-person education, avoiding the use of shifts or online classes. Within the scope of this article, we aim to examine the innovative approach of multipurpose spaces, which can play the dual role of standard educational spaces during epidemic emergencies and adaptable environments under ordinary circumstances. Different desk arrangements and their impact on the capacity of spaces in both contexts will be explored.

In many established educational settings, the addition of new multipurpose spaces often runs into space resource limitations [22]. Therefore, the development of new design strategies to efficiently deal with emergency situations, such as that caused by the COVID-19 pandemic, becomes crucial.

During the COVID-19 pandemic, the predominant strategy in schools was to maintain adequate social distancing between students, generally set at one meter [23]. This was achieved through two different arrangements of students within spaces: static and dynamic arrangements.

2.2 The static arrangement (comparable with the ordinary configuration)

In this setting, students are required to wear masks as they move along predetermined routes within the classroom. However, they are allowed to remove them once they are seated at their desks. To be more specific, masks must be worn whenever students stand up, such as to approach the teacher, move to the blackboard, or in situations where physical distancing is impractical.

To highlight the equivalence between the static and the ordinary arrangement, let us consider, as an example, a usual arrangement with desks of size 70 × 50 cm (Figure 4). In this configuration, a distance of 60 cm is ensured between desks in the same column in emergency situations [24], thus ensuring that the distance between students seated is 110 cm. This measure even exceeds the meter required in the static arrangement.

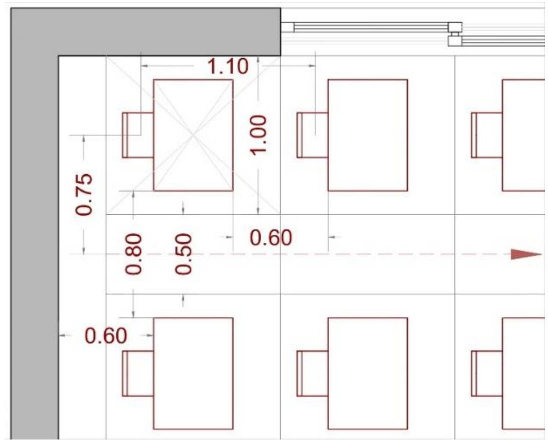

Figure 4. Schematic layout of desk arrangement in classrooms with specified distances to mitigate contagion risk

2.3 The dynamic arrangement

In this configuration, students can avoid wearing masks not only while sitting in their seats, but also while moving along predetermined paths within the classroom.

The size of the classroom during an outbreak depends on the required safety distance, which is influenced by the size of a bench module. A standard bench, with a coffee table of 70 × 50 cm and a chair of 40 × 40 cm, defines a rectangular module of 130 × 100 cm. This module is bounded by parallel straight lines spaced 30 cm from the front and back edges and 15 cm from the side edges. The center of the bench coincides with the center of the module (Figure 5).

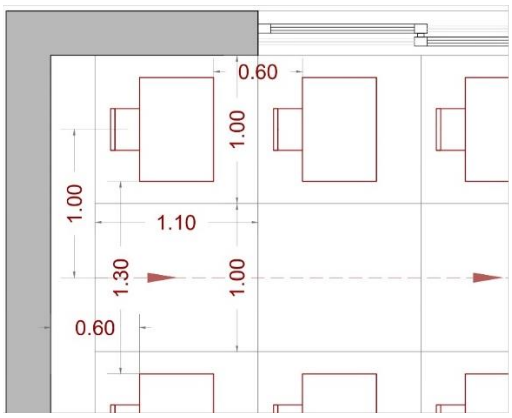

Figure 5. Detail drawing of a dynamic desk arrangement with safety distances and path widths for enhanced student mobility

In an epidemic situation, a classroom can be reorganized into a matrix of modules consisting of 6 columns and 4 rows (Figure 6). Two columns are designated for student-accessible aisles. This provides an efficient layout for the desk area. This area is divided into two columns flanking the side walls and two columns grouped in the middle. At the bottom, there is an interactive area that includes the teacher's desk, blackboard, and entrance. The total depth of the interactive area is equal to that of two modules, ensuring a distance of at least 2 linear meters between the chair and the nearest desk [25]. The ideal location of the desk is in the corner opposite to the entrance, to facilitate student movement and optimize space in the interactive area.

In the static arrangement (equivalent to the ordinary arrangement), another column of 6 students can be added, thus halving the width of the longitudinal path modules of the previous dynamic arrangement (1.30 m × 1.00 m). However, in order to maintain this static arrangement during an outbreak, it is necessary for students to wear masks even while moving around the classroom. In summary, considering the two arrangements mentioned (dynamic, static), the number of students in the same classroom (9.10 m × 6.00 m) can be increased from 24 in the dynamic arrangement (Figure 6) to 30 in the static arrangement (Figure 7). Note that the minimum and maximum number of students per classroom are 15 and 25, respectively, as specified in Ministerial Decree No. 141 of June 3, 1999 [26].

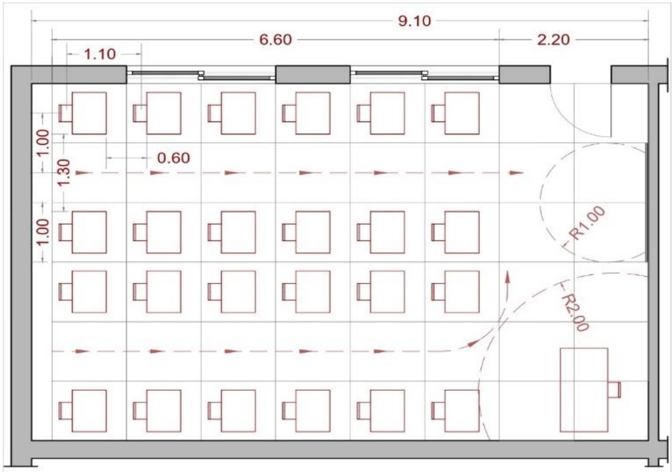

Figure 6. Dynamic classroom layout enabling mask-free movement with maintained interpersonal distance of one meter

Figure 7. Standard desk layout for a maximum of 30 students in a 9.10 × 6.00 m classroom with accessibility considerations

In the dynamic configuration, the organization of desks is in columns, with a corridor positioned between each pair of columns. This structure facilitates the free movement of students through the longitudinal aisles, avoiding close interaction with other classmates. However, in cases where the columns are grouped into three or more adjacent units, it is necessary to implement cross passages to ensure safe access for students seated in the central area.

The introduction of crosswalks between rows of desks can result in a reduction of the space efficiency of the classroom. As an example (Figure 8), let us consider the transformation of an ordinary arrangement with a matrix of 6 columns and 6 rows into a dynamic configuration. In this scenario, it becomes essential to transfer a column of desks to the multipurpose space (see next section) to allow for the widening of the longitudinal aisles and the creation of three cross passages between rows of the central columns. This process results in a decrease in the number of students from 36 to 21.

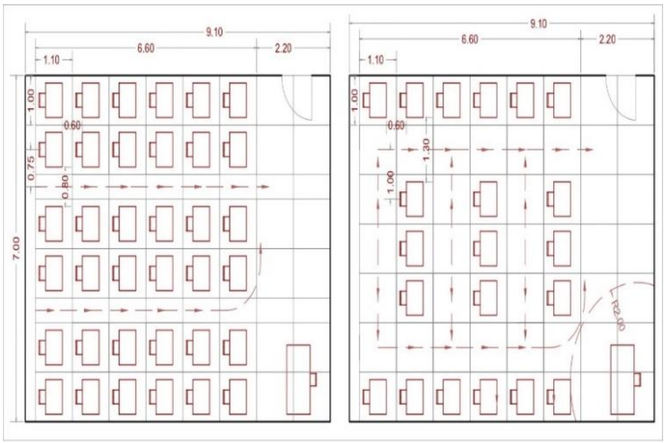

Figure 8. Comparative drawings showing the conversion from static to dynamic classroom layouts to ensure safety distances

Since 21 is not a divisor of 36, regularizing the number of students in all classrooms after reconfiguration may prove problematic. This can generate organizational and teaching challenges, such as the need to form groups of varying sizes or to allocate additional space for laboratory or group activities.

Therefore, it is crucial to carefully weigh the maximum number of columns in a dynamic arrangement. In general, it is recommended to limit the number of columns to five in order to exclude the need to create crosswalks and to ensure uniformity in the number of students in different classrooms. This consideration is based on reasons both organizational and educational, aiming to preserve a cohesive and efficient learning environment even in epidemic or emergency situations.

3. MULTIFUNCTIONAL SPACE

The poly functional (P) space represents our innovative proposal to solve the problem of adapting the arrangement of desks in teaching classrooms to different needs. Its flexibility is manifested through the rapid transformation from static arrangement (equal to ordinary arrangement), to dynamic arrangement during an epidemic situation.

Fixed parameters:

-Depth of the interactive zone: where the teacher's desk, blackboard and entrance are located.

-The distance between the rows of desks, set to 60 cm as a convenient distance for escaping.

-Uniformity of classrooms: Classrooms should have the same number of students along with the same matrix of the arrangement of desks before and after the class transformation.

3.1 Calculation of the total number of ordinary classrooms after transfer

Total number of students before transfer

$$(M) = R \times C \quad (1)$$

Number of transferred Students (C1): the number of students in a column

Number of students after transfer

$$(N) = M - C1 \quad (2)$$

Number of students in ordinary classrooms after transfer

$$(T) = N/R \quad (3)$$

Justification for the Limit of 5 Columns: The choice to transfer only one column is constrained by the need to ensure safety in the longitudinal paths of the dynamic arrangement. Limiting the maximum number of columns in the static arrangement to 5 ensures that once one column is transferred, the width is appropriate to maintain the distance of at least one meter in the longitudinal paths. This constraint is crucial for a smooth transition from the static to the dynamic arrangement, preserving the safety of students while moving around the classroom.

Example: Consider an ordinary arrangement with R = 5 rows and C = 6 columns. We calculate:

M = 5 × 6 = 30

C1 = 5

N = M - C1= 30 - 5 = 25

T = N/R = 25/5 = 5

3.1.1 Observations

The transformation from static to dynamic arrangement is optimal when the number of columns is no more than five columns, ensuring sufficient width for longitudinal paths. If the number of columns is more than 5, the transformation may become more complex, especially in large rooms such as libraries.

Spacing of at least one meter in longitudinal paths is essential to ensure safety during movement.

This approach provides flexibility in managing school spaces, balancing the needs of static layout with the need to adapt to epidemic situations. Limiting the number of columns to five is essential to ensure a smooth transition from the static to the dynamic arrangement. When a column of desks is removed from the static arrangement, there is an opportunity to evenly distribute its width to the two pre-existing longitudinal paths of the static arrangement. This results in a dynamic arrangement with a safe distance of at least one meter between students walking the longitudinal path, and those seated in adjacent desks. For example, consider a width of 86 cm for the longitudinal path in the static arrangement, when a column is transferred to the multipurpose room, the width of this column (86 cm) is divided equally between the two longitudinal paths (43 cm each). This value, added to the initial path width, brings each path to a total width of almost 130 cm. Halving this value, we get 65 cm, and adding this figure to the 35 cm (half the width of the bench in which a student is sitting), we get a safety distance of 100cm. This measure corresponds to the minimum distance between the axis of the longitudinal path and the student sitting at the nearest desk, thus ensuring the necessary safety.

3.2 Configuring the ordinary arrangement of desks

Based on calculations dictated by regulations, decrees and safety considerations, we have developed an optimal configuration to transform the ordinary arrangement, which can be likened to a static arrangement, into a dynamic arrangement.

Fixed Parameters:

-Size of the bench b x c: 0.50 × 0.70 meters

-Modulus of the counter area: 1.00 × 1.10 meters

-Depth of the interactive area: 2.20 meters. This value is constant in both configurations and ensures a safe distance of at least two meters between the teacher and the nearest student in the dynamic arrangement

-Maximum number of bench columns: 5

-Two Longitudinal Paths: Each b/2 wide, with the condition that students can access them directly, making it necessary for the columns of desks to flank these two paths. The effective width= 0.80 m

-Complete Safety Distance (Cr): 0.30 m for the last row of desks

3.3 Calculation of classroom size with ordinary arrangement (30 students as maximum capacity)

Width (L) of the classroom: 6 modules, equal to 6.00 meters.

Depth (F) of the classroom: Depth of the desk area (Pb) + Depth of the interactive area (Pi) + complete safety distance (Cr).

Therefore, F = Pb + Pi + Cr = 6.6 + 2.2 + 0.3 = 9.10 meters.

Thus, the total size of the classroom is F * L = 9.10 * 6.00 = 54.60 square meters.

3.4 Transformation to dynamic disposition

The transformation takes place through the elimination of a column of desks, transferring it to the multipurpose classroom. This unifies the width of the longitudinal pathways with the other modules, enlarging it to 1 meter. The effective distance between the desks of the two columns flanking the pathway becomes 1.30 meters, respecting safety during epidemics and contingency situations.

In the context of designing educational spaces in epidemic or contingency situations, the inherent complexity of evenly redistributing students emerges, a complexity that is intimately linked to limiting the number of columns. It is crucial to stress the importance of keeping the maximum number of columns within the limit of 5 (or its multiplication in larger environments such as a reading room). This constraint proves crucial in simplifying space management, mitigating the complexities associated with student redistribution.

A concrete example is outlined in the examination of a configuration consisting of 5 columns and 6 rows, corresponding to a total of 30 students (Figure 9). Through the transfer of one column, comprising 6 students, a residual of 24 is obtained. In this context, the optimal number of ordinary classrooms turns out to be 4, allowing an even redistribution of students. Performing a column transfer from each of the 4 classrooms to the multipurpose room would result in an even distribution with 24 students in the multipurpose space. This approach ensures that all classrooms maintain a uniform matrix, characterized by 4 columns and 6 rows, even after the transfer.

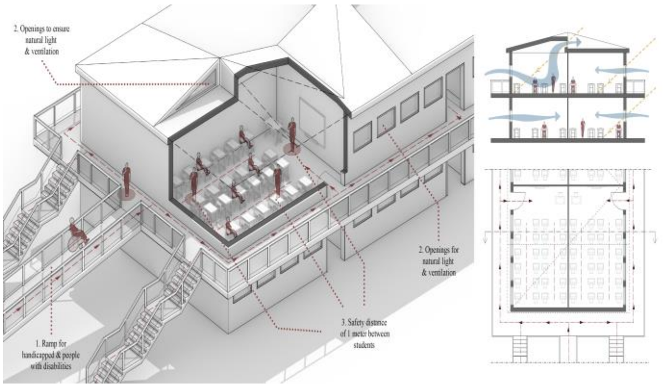

Figure 9. 3D model and sectional analysis of a dynamic desk arrangement assessing accessibility, natural light, and ventilation for enhancing well-being and infection control

It should be noted that while the number of rows can theoretically be unlimited, external factors such as laws, decrees, ventilation requirements and visibility of the board can impose practical limits. Consequently, the optimal configuration depends on a combination of internal and external parameters, requiring flexibility to adapt to different conditions. This flexibility is essential to ensure the creation of school environments that are safe, efficient and meet regulatory standards.

Figure 10. A drawing showing the difference between the arrangement of desks in four adjacent classrooms in epidemic situations and normal conditions

In the upper section, the standard arrangement of desks in four adjacent classrooms (Figure 10), typical for normal circumstances, is depicted along with a designated multipurpose space for extracurricular activities. In the lower section, the dynamic arrangement of the same classrooms is shown following the relocation of surplus students from the regular classrooms to the multipurpose space.

4. CONCLUSIONS AND IMPLICATIONS

The research revealed the crucial role of a multifunctional space, highlighting its relevance in epidemic situations and normal conditions. Compared with alternative options such as movable or collapsible partitions which have set of disadvantages, these include high cost ranging from 160$ to 320$ per 1 m^2, the need for a storage space when they are not in use, which can be problematic in smaller areas, time-consuming and labor-intensive installation and removal. Furthermore, the limited sound insulation and durability make them susceptible to wear and tear over time and less effective to be used in classrooms. Multifunctional space has been shown to be advantageous in emergency management, allowing active reorganization of space without requiring outside intervention, only requires relocating existing furniture from other classrooms with no additional cost.

The interactive flexibility of the multipurpose space was highlighted, presenting an inherent adaptability that engages students in the process of rearranging environments. However, it is important to note that such versatility is constrained by critical factors such as visibility and audio, highlighting the importance of carefully thought-out design.

In normal situations, the multipurpose space emerges as a valuable resource. Going beyond modes such as online teaching or rosters, it offers significant benefits in terms of effectiveness, interaction, motivation and inclusion. Its management involves not only physical spacing in classrooms, but also includes the use of larger spaces, with measures such as one-way movements and disinfection procedures.

Ventilation and class duration remain crucial aspects in ensuring a safe and healthy environment. In this context, the multi-purpose space emerges as a strategic solution to maintain high teaching standards, both in emergency situations and under normal conditions.

In conclusion, the design of multipurpose spaces emerges as an effective and sustainable strategy to ensure safety and continuity in education, allowing a safe distance of 1 meter between students in both fire emergencies to ensure a safe evacuation, and pandemics to prevent infection among students. Investment in proactive design solutions proves crucial to foster continuous learning that is safe and adaptable to the changing needs of the educational environment.

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