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PREVENTING COVID-19 SPREAD IN SCHOOL BUILDINGS USING BUILDING INFORMATION MODELLING: A CASE STUDY

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Abstract

During the last years, many studies focused on automated processes for compliance checking intended to replace the current design verification practices. So far, the verification of projects in the Architecture, Engineering, Construction, and Operation industry has largely consisted of manual processes, which result in laborious, costly, and error-prone. The compliance checking process addresses the project's whole life cycle, from the design phase to the end of life. Previous researches show the applications of a Building Information Model Checking referring to the compliance with several national and international normative to meet standards requirements. This paper proposes an innovative approach to evaluate the compliance of school buildings with the measures to prevent and control the spread of Coronavirus, one of the most significant pandemics. A case study is then presented to validate the method. The school building is modelled using Revit software. Dynamo is employed as a visual scripting tool to customize the mathematical formulations of each safety rule from different standards for COVID-19 prevention. Revit and Dynamo are coupled to conduct the compliance checking. The methodology herein proposed allows for verifying the school environments showing their compliance with safety standards. Although the World is coming out of the COVID-19 pandemic, this approach could be used to face other waves or different types of pandemics.

Keywords

Building Information Modelling, Visual Programming Language, Code checking, COVID-19.

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1. INTRODUCTION

Coronaviruses (CoVs) are enveloped positive-strand ribonucleic acid viruses that can infect humans and animal species [1]. The Chinese Centre for Disease Control and Prevention confirmed a novel coronavirus named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), closely related to CoVs and highly contagious [2]. The World Health Organization (WHO) declared a public health emergency of international concern on 30 January 2020, and the disease named "COVID-19" was then announced [3]. To date (April 2022), there have been more than 500 million confirmed cases and more than 6.4 million deaths confirmed by WHO [4].

In such a scenario, healthcare systems, infrastructures and educational systems face great challenges in providing essential services. Governments have immediately implemented emergency plans to deal with the pandemic trying to reduce the impacts on people's mental and physical health and financial resources. This results in issuing different guidelines to face the virus spread. Rigorous programs to control the infection are needed to minimize the risks of COVID-19 spread, while new ways of working support the recovery of essential services during the pandemic. Adopting organizational, environmental and personal measures optimizes emergency management allowing for normal activities and reducing the contagion risk among people [5]. The main center for research, control and technical-scientific consultancy in the field of public health in Italy (Istituto Superiore di Sanità, ISS) has defined behavioral rules for personal protection, such as the use of masks and gloves, social distancing and hand sanitation with alcohol-based products. ISS published *Guidelines for the prevention and management of indoor environments in relation to the transmission of the SARS-CoV-2* [6].

In Italy, schools have implemented several processes for the re-functionalization of spaces in order to make them usable during the COVID-19 pandemic. School buildings must respect specific rules to be safely used. The non-compliance with regulations might compromise the quality of the built environment and the quality of the services delivered, which can impact health [7]. Furthermore, compliance issues could lead to delays in design, extra costs, as well as project reworking and poor quality [7]. For example, bigger classrooms were built by breaking down dividing walls, or new classrooms were created using corridors. Considerable resources were spent to adapt and use different buildings when this was not technically feasible. If these approaches were not possible, the students would take turns with a reduction of school hours.

The aim of this paper is to define a practical method to automatically check the school buildings compliance with the measures to prevent and control the spread of Coronavirus using the Building Information Modelling (BIM) approach. BIM is able to optimize processes and obtain higher quality products and performance by managing data requirements in an alphanumeric way, for example, through code-checking procedures. 3D-BIM models can also be coupled with Visual Programming Language (VPL) software tools to perform advanced compliance-checking processes. Here, different guidelines for struggling with the spread of COVID-19 were analyzed, and control scripts were modelled using VPL scripting. BIM-VPL coupling is then used to analyze the performance of buildings and evaluate optimal use conditions of school buildings. Then, this study provides a suitable methodology to counter the epidemiological diseases spread within the working environment in general, as it is replicable depending on different types of parameters adopted.

2. BIM AND VPL APPROACH

COVID-19 has dramatically affected the world economy, industry, and citizens. Nevertheless, digitization is aiding many businesses to adapt and overcome the current situation caused by the pandemic [8].

Building Information Modelling (BIM) is one of the most promising developments in the Architecture, Engineering, Construction and Operation industry [9–15]. BIM consists of expanding 3D models to computable nD models capable of simulating each building's lifecycle process: planning, design, construction, and operation. 3D BIM concerns not only modelling buildings, infrastructures or services: it allows for performing specific analyses based on the geometrical information of the model, such as 3D visualization, clash detection and code checking. Clash detection is the analysis of possible geometric interferences among objects, models and drawings, while code checking is the analysis process of potential data inconsistencies between objects, models and drawings compared with rules and standards [16]. So far, the process of checking these parameters in the industry has largely been manual, laborious, costly, and error-prone [17–19]. Object-oriented and parametric modelling provides a way to automate code-checking procedures in building designs, as it is possible to associate parametric rulings to the elements that compose the virtual model, ensuring the process runs correctly [20].

Opportunities exist to extend building performance simulations and code-checking processes with scripting environments. Visual Programming Language (VPL) software tools are now considered of high potential since they have geometric modelling functionalities together with scripting capability based on a simplified user interface. Most design tools support one or more scripting environments and are able to use a VPL as middleware bi-directionally linked to BPS tools, which results in an integrated dynamic model [21]. Actually, VPL could also be used as a BPS tool since it provides the capacity for scripting. Tools like Dynamo allow for more complex rules to be created without adding the need to code programming. For example, Röck et al. [22] established an automated link between the LCA database and the BIM model using Autodesk Dynamo as a visual scripting software. The authors calculated the environmental impacts of the case study building directly in Dynamo. Cavalliere et al. [23] use VPL tools to conduct code compliance checking to evaluate building flexibility levels by introducing six selective criteria in a BIM environment. In that case, different algorithms are implemented in a VPL tool, which is bi-directionally linked to the BIM environment where the BIM elements already host the semantic information required.

Code checking has been the subject of scientific research for years and has been put into practice in numerous projects [24]. However, no studies have focused on the use of BIM and VPL to deal with an epidemiological pandemic from the side of buildings design, which is the goal of this paper.

3. METHOD

The aim of the study is to define a practical ruleset for school spaces design in accordance with the safety measures tackling the SARS-CoV-2.

The method consists of three main steps. The first step is discussed in Section 2.1. It aims to define the relevant safety rules to be applied to school buildings. Mathematical formulations are provided for each ruleset, and they are based on Operational Manual and Guidelines. In the second step (Section 2.2), a BIM model of the Michelangelo school building is developed with Autodesk Revit. Step three (Section 2.3) concerns the application of the operational safety rules through the Code Checking process. In particular, the checks are carried out by identifying customized algorithms implemented in Dynamo software. Specific additional parameters are implemented in the Revit model to allow the performance of the scripts. Then, BIM software is linked to VPL software to perform the calculation automatically, as shown in Section 2.4. Autodesk Dynamo is employed as a visual scripting tool to customize the mathematical formulations of each safety rule. The scripting tool automatically performs the calculation by reading the design properties and geometry from the BIM. The methodology can be implemented not only in reference to the present case study, which is the compliance to the standards identified for the prevention and mitigation of epidemiological diseases. In fact, the present method can be applied according to any buildings' needs, such as regulatory updates or exceptional occurrences.

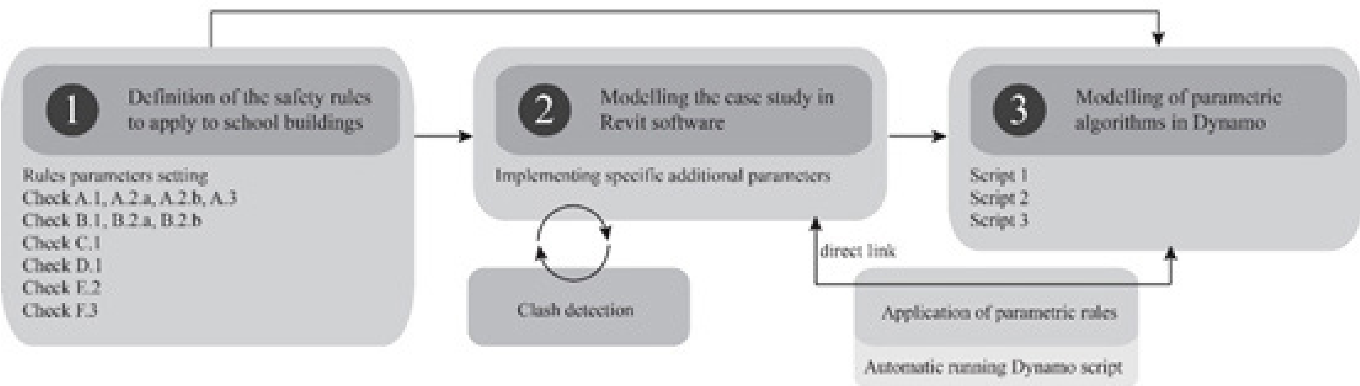

Fig. 1. *Research method.*

4. CASE STUDY

The case study is the Michelangelo Secondary School in Bari, Italy. It was built in the 1990s with a load-bearing masonry structure with bricks in porous clay. The building has a basement and three above-ground floors for a total gross area of approximately 7000 m^2. The upper ground floor hosts the administrative offices. The auditorium, the laboratory, a secondary atrium, the toilets and the gym extend northern. On the western side are a classroom for support activities and a laboratory. Finally, to the south is the lecturers' room, a secondary room, the infirmary and the toilets. The next two floors are for classrooms and can be reached via two internal stairs. On the first floor, there are fourteen classrooms and three laboratories, while on the second floor, there are twelve classrooms. The basement consists of the caretaker's accommodation, a refectory, the gym, the changing rooms, and the office of the physical education teachers.

4.1. DEFINITION OF SAFETY RULES

The trend of infections has forced Italian Institutions, in certain periods of higher risk, to close school buildings and apply E-learning through online classes. Once the epidemiological curve fell below the pre-established safety levels, it was possible to return to opening school buildings while considering the necessary precautions and enforcing general rules for safety. The operational rules about the schools' spaces used for this paper come from different operating manuals: the guidelines of the Veneto and Lazio regions, the ISS documentation, and the Italian Scientific Technical Committee guidelines. According to the safety guidelines, the following Table 1 shows the checks performed for the different environments considered.

Locals	**Script**	**Checks**	**Criteria**
A Classroom	**Script 1**	*A.1.* Distance check between fixed scholars' seats	Minimum distance between scholars = 1m
	Script 2	*A.2.a.* Dynamic zone dimension check	Minimum dynamic zone dimension = 2.5m
		A.2.b. Rime buccali distance check between teachers and scholars	Rime buccali distance between teachers and scholars = 1.5m
	Script 3	*A.3.* Maximum room capacity check	Room area on area per person (equal to a circle of radius r = 1m) = maximum room capacity
B Laboratory	**Script 1**	*B.1.* Distance check between fixed scholars' seats	Minimum distance between scholars = 1m
	Script 2	*B.2.a.* Dynamic zone dimension check	Minimum dynamic zone dimension = 2.5m
		B.2.b. Rime buccali distance check between teachers and scholars	Rime buccali distance between teachers and scholars = 1.5m
C Auditorium	**Script 1**	*C.1.* Distance check between seats	Minimum distance = 1m
D Staff room	**Script 1**	*D.1.* Distance check between fixed teachers' seats	Minimum distance = 1m
E Connecting spaces	**Script 2**	*E.2.* Connecting spaces dimension check	Area per person > 1.25 m^2
F Gym	**Script 3**	*F.3.* Maximum room capacity check	Room area on area per person (equal to a grid of 2m x 2m) = maximum room capacity

Table 1. *Summary of the scripts applied to the different locals.*

4.2. MODELLING THE CASE STUDY

The building modelling has been carried out using Autodesk Revit software, starting from two-dimensional CAD drawings. Within the BIM, the spaces listed below are modelled according to the layouts used earlier than the application of the measures for containing the virus: A) Classroom; B) Laboratory; C) Auditorium; D) Staff room; E) Connecting spaces; F) Gym.

4.3. MODELLING OF PARAMETRIC ALGORITHMS IN DYNAMO

After modelling the case study and identifying standards to be applied, the following scripts are implemented in Dynamo. The Script n. 1 (distance check) allows verifying the safety distances between the fixed individual locations. The scripts aim to determine which stations can be used safely and which should be left free. Results can be displayed graphically and textually in Revit environment using the appropriate nodes shown in the figure below.

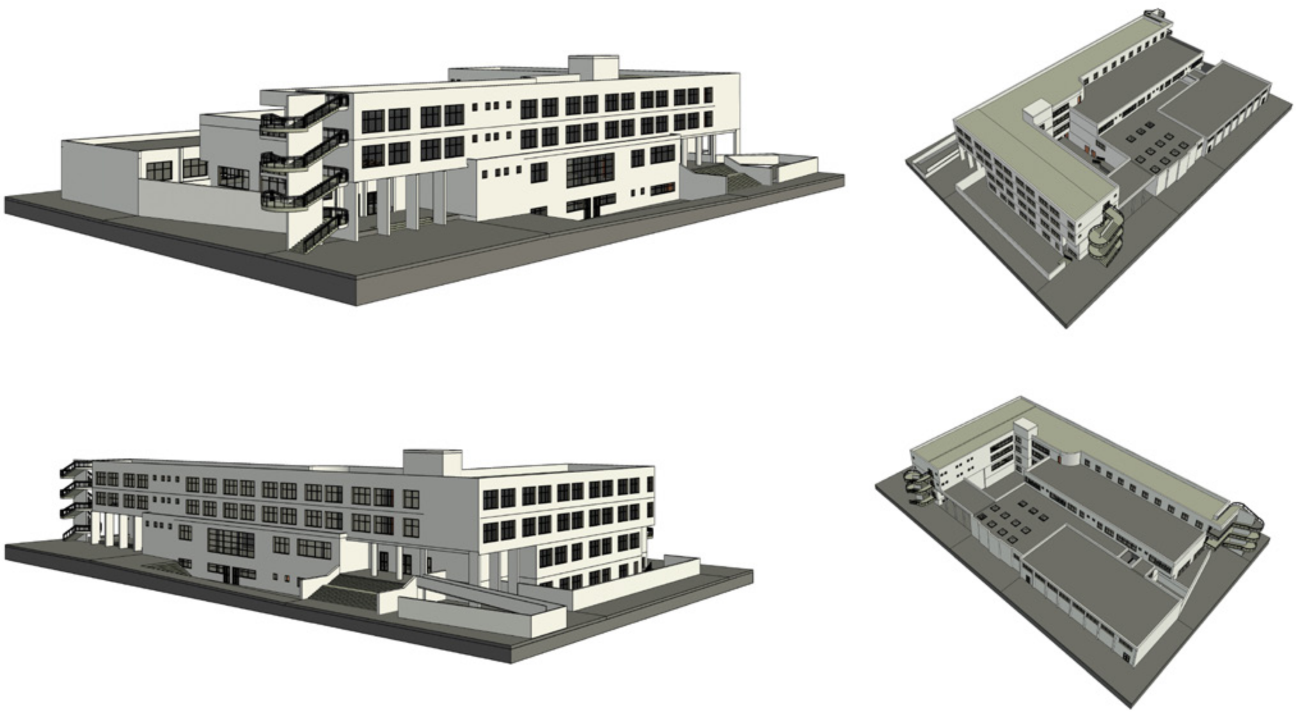

Fig. 2. *Revit Model.*

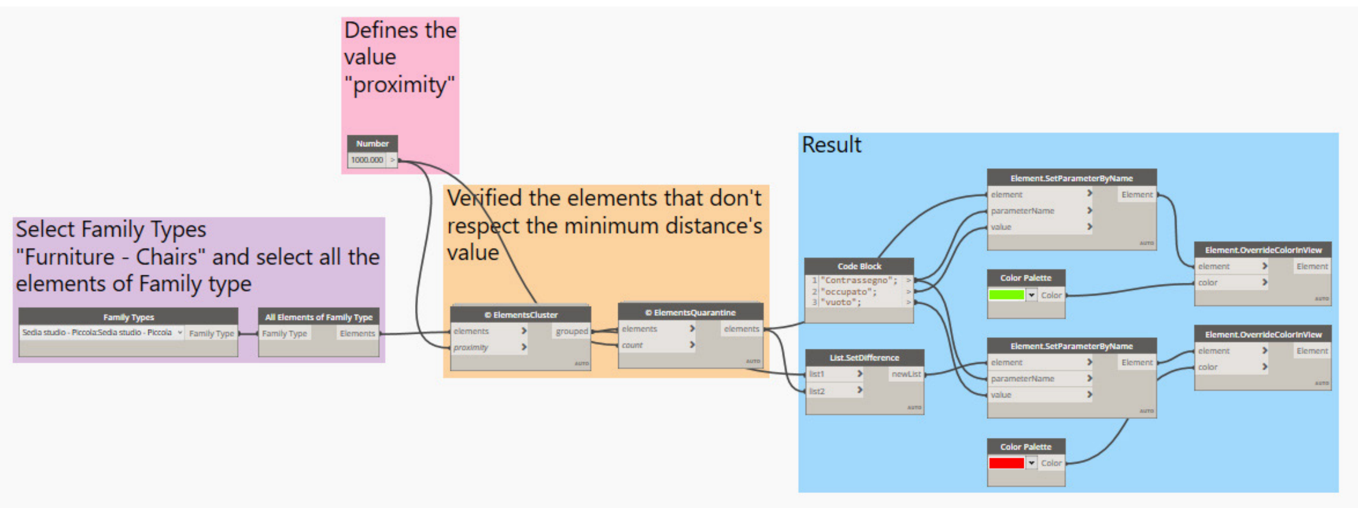

Fig. 3. *Script 1.*

Script n. 2 (critical areas dimensions check) allows verifying that the room's dimensions do not exceed the limit laid down in safety guidelines to mitigate crowding risk. The script consists of two parts: the first one concerns the identification of room lengths and widths; the second one allows checking whether the room's lengths and widths comply with the minimum values set. Results can be graphically displayed in Revit environment through the objects colors. Results are also textually shown in the properties of model "rooms" (rooms are identified as objects with several properties in Autodesk Revit).

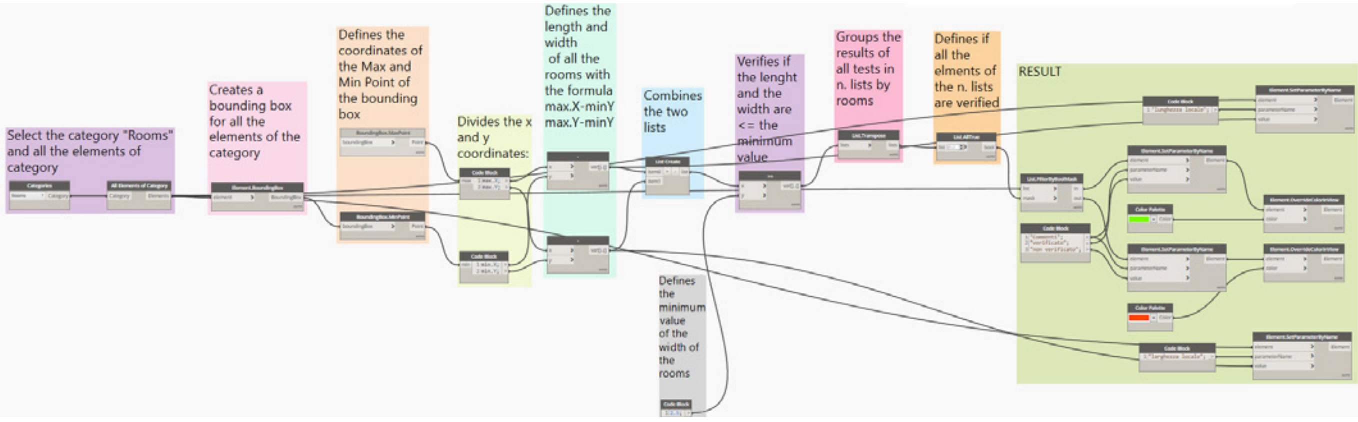

Fig. 4. *Script 2.*

Script n. 3 (maximum occupancy check of rooms) allows verifying the maximum space occupancy according to the safety rules on social distancing. Each zone is identified as a "room" in the Revit environment. The script analyzes all the rooms in the BIM model.

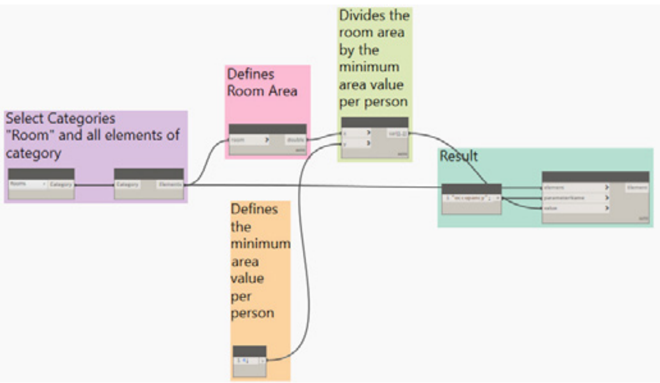

Fig. 5. *Script 3.*

Before performing the code-checking process, it is necessary to carry out a preliminary phase in order to ensure the correct script functionality: the model validation phase. This phase consists of implementing customized parameters into the BIM model to perform the code-checking activity. For the present case study, shared parameters are used, which can be written on independent files to be reused in any project and Revit family objects. Thereby, it is possible to implement these specific parameters in different BIM models to perform similar checks. Hence, the reproducibility of the present method in other case studies is guaranteed. Here, the shared parameters implemented in the BIM model are the following:

- occupancy: maximum allowed number of people in a room, which is determined by the ratio between the net area and the allowed area per person;
- room width/room length: width/length of the dynamic space identified within the different rooms or the space between teachers and scholars;
- seats distance: distance between fixed positions in a room.

4.4. OPERATIONAL APPLICATIONS TO COUNTER SARS-COV-2

Once the scripts for code-checking activities were identified, they were applied to the information model. First, the checks are carried out on the rooms' generic layout to verify the compliance with the guidelines for the containment of the Coronavirus. Then, the same verification is applied to the same rooms with a new layout meeting the indications for the prevention of the virus spread.

4.4.1. CLASSROOM: CHECK A.1

Considering the public school Michelangelo in Bari, classrooms have the same layout and dimensions in most cases. Hence, only one kind of classroom is analyzed here to show the proposed methodology.

The first check carried out concerns the compliance with the safety distances in the static area, which is the area intended for students. First, the check is carried out on a layout representative of the real state of a generic classroom of the building under investigation. Applying the proposed algorithm shows that the school benches' position in the real condition does not comply with the safety rules for preventing the spreading of the virus. As illustrated in the figure below, the algorithm highlights in red color the stations to be kept free to meet guidelines requirements.

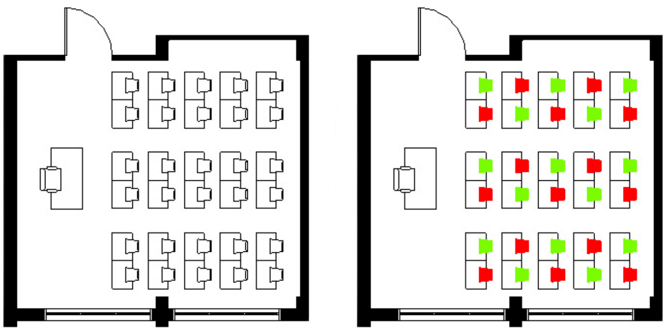

Fig. 6. *Left: layout of the room in the real condition; right: the graphic result of the check application.*

Subsequently, the design criteria necessary to mitigate the virus spread are applied to the aforementioned layout. Here, three different scenarios are taken into account:

- first scenario: precautionary scenario, which involves the distance between benches rows equal to 1 m, while the distance between benches columns equals 0.6 m;
- second scenario: in this case, the distance between the students' *rime buccali* (namely the distance between the mouths of two close people) is set as a reference measure of 1m, while the distance between benches columns is equal to 0.6 m;
- third scenario: in the last scenario, benches are arranged in double rows in order to ensure a distance between the *rime buccali* equal to 1 m; then, benches lines are interspersed with a corridor with a minimum width of 0.6 m.

The check applied on the new layouts returned a positive result in all three scenarios showing that stations can be used safely. BIM processes allow for immediate comparisons between different design alternatives. As such, designers have an effective process to perform the best possible solution. In particular, the real-time comparison between the different scenarios would allow for increasing classroom occupancy: although all three new proposed scenarios meet the rules on social distancing, the application of the third scenario allows to host 20 scholars, which is 5 more than the first scenario. This condition could ensure that all students take a class instead of e-learning lessons. If the classroom layout cannot be modified, the automated check identifies the workstations to be kept free to meet the social distancing rules, which are then labeled with red color by the algorithm proposed, as shown before.

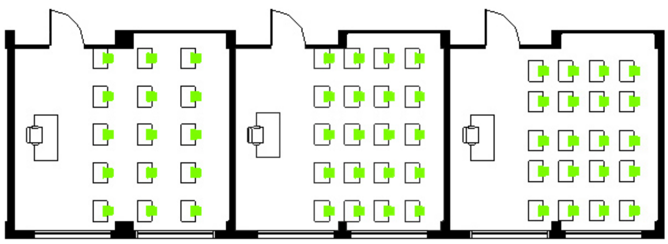

Fig. 7. *From left to right: scenario 1, scenario 2, and scenario 3.*

4.4.2. CLASSROOM: CHECK A.2.A

The classroom's dynamic space is the area between the wall behind the blackboard and the *rime buccali* of students from the first line. In order to define the dynamic zone in Revit, a "Room" is created within the classroom to circumscribe this specific zone. The script applied in this case automatically returns the width and length of each school building's room labeled as a dynamic zone. Then the script returns a result of compliance or non-compliance with the safety rules considered.

Checks are first carried out on the layout representing the typical classroom of the school building. Subsequently, checks are carried out on the layouts analyzed in the previous Check A.1.a. In particular, the changes consider the dynamic space distance of 2.5 m (Tab. 1). Here, checks reported positive results for both the typical and redesigned layout.

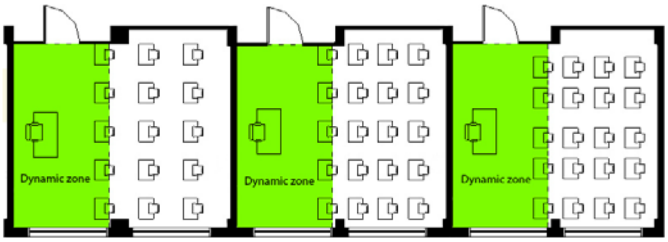

Fig. 8. *From left to right: scenario 1, scenario 2, and scenario 3.*

4.4.3. CLASSROOM: CHECK A.2.B

This check concerns the distance between the teachers' *rime buccali* and first-line pupils' *rime buccali*: such a minimum distance must equal 1.5 m (Tab. 1). The algorithm works similarly to Check A.2.a. First, a "Room" is created for the area under investigation in Revit. Hence, the script verifies whether the room complies with the minimum dimensions required. Results report negative outcomes for the typical classroom layout, which means that teachers are typically quite close to the first-line students. On the contrary, in the case of the modified layouts according to the safety guidelines, the distances are fully compliant with the safe use of the classroom.

4.4.4. CLASSROOM: CHECK A.3

The last check for the classrooms is carried out considering the size and area per person necessary to define the maximum number of users present simultaneously (room capacity) and ensure social distancing. The limit imposed by the guidelines, as reported in Table 1, considers the ratio between the room's net area and the area per person equal to a circle of radius 1m. In this case, the algorithm performs the calculation by returning the maximum number of students allowed to stay simultaneously in the classroom.

4.4.5. LABORATORY: CHECK B.1

Regarding laboratories, the guidelines identify the same rules for classrooms (Tab. 1). Therefore, the application of the scripts does not vary. In this case, the check is carried out on the typical laboratory layout. This check involves the verification of the minimum distance between scholars, which must be equal to 1 m (Tab. 1). Results show that some seats cannot be safely used as they do not comply with the rules on social distancing. As illustrated for the previous check A.1, the algorithm highlights in red color the stations to be kept free to meet guidelines requirements. As such, taking into consideration some fixed workstations, the ones marked as "empty" are eliminated, effectively halving the capacity of the laboratory.

Unlike classrooms, laboratories are usually organized with fixed workstations hosting, for example, instruments and computers whose position cannot be changed. Therefore, the verification is only carried out on the real laboratory layout without comparing it with redesigned layouts.

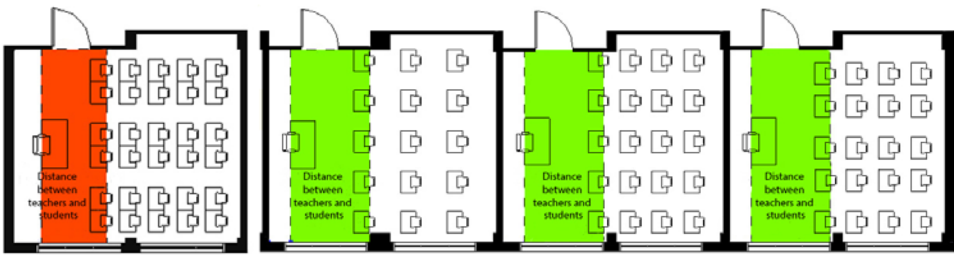

Fig. 9. *From left to right: typical classroom, scenario 1, scenario 2, and scenario 3.*

4.4.6. LABORATORY: CHECK B.2.A

The same verification of check A.2.a is applied here for the laboratories. As for the previous check B.1, the verification is only carried out on the real laboratory layout without comparing it with redesigned layouts. The dynamic area dimension is verified using the same methods of classrooms, and the checks carried out returned positive results.

4.4.7. LABORATORY: CHECK B.2.B

The last check for the laboratory concerns the distance between teachers' and scholars' *rime buccali*, which has to be not less than 1.5 m (Tab. 1). In this case, the Dynamo algorithm returned a negative result, which means that scholars are too close to each other. Layout checks are then carried out by halving the room capacity with empty workstations: in that case, the result is positive as the distance between the occupied stations has actually increased.

4.4.8. AUDITORIUM: CHECK C.1

In the case of the auditorium, we refer to the Ministerial Decree of 19/08/1996 as amended: «Approval of the technical fire prevention rule for the design, construction and operation of entertainment and public entertainment venues». This standard is applicable to premises open to the public for entertainment with a capacity exceeding 100 people or with a gross surface area exceeding 200 m^2. The auditorium under investigation falls into these shapes. According to the standard, there can be a maximum of 10 rows composed of a maximum of 16 seats. Seats must be spaced at least 0.8 m apart. They also must be at least 1.2 m away from the walls. If a distance of 1.1 m between rows is achievable, it is possible to consider 20 seats per row for a maximum of 15 rows. Finally, corridors with a minimum width of 1.2 m must be provided if seats are arranged in sectors. The seat width equals 0.5 m for seats with armrests and 0.45 m without. The checks are carried out taking into consideration that the distance necessary to guarantee a safety condition is equal to 1 m. The verification of the real condition considers two hypotheses:

- first scenario: a distance between rows of 0.8m is considered. In this case, the check shows a drastic reduction of the usable seats, equal to a quarter of the total;
- second scenario: In the second case, a distance of 1.1 m between the rows is considered.

The verification shows only a halving of the seats that can be used safely.

In the case of the auditorium, seats can generally be fixed or movable. In the case of movable seats, they can be reconfigured to comply with safety measures. In the case of fixed seats, the checks carried out can be used to indicate which one must be kept free for compliance with safety conditions.

4.4.9. STAFFROOM: CHECK D.1

In the case of the staffroom, the following real layout is used for verification. The check here shows the unusable workstations according to the safety rules (Tab. 1). The layout is therefore redesigned considering a distance of 1.15 between the stations. In this way, the verification of the new layout shows that all stations can be used respecting the social distance, as highlighted in the following figures.

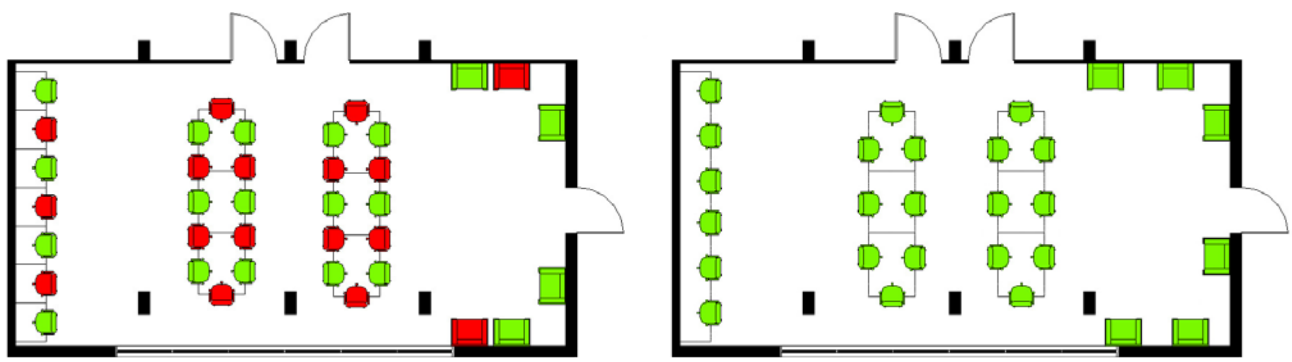

Fig. 10. *Staffroom. Check D.1. left: the unusable workstations according to the safety rules are shown in red colors; right: redesigned layout.*

4.4.10. CONNECTING SPACES: CHECK E.2

In this case, the dimension of all the school connective spaces is analyzed. In the case of corridors, the following condition must be respected: area per person > 1.25 m^2. By checking connecting spaces dimensions, it is possible to identify which can be used safely in two-way traffic and which must be necessarily used in one direction. The latter occurs in connection spaces with a high risk of gathering, as in the case of the entrance and exit from the school building. The checks applied to school building corridors under investigation report the following results:

- mezzanine floor: the stairs connecting the east area to the main atrium do not meet safety rules;
- first floor: the corridor of the southern classrooms and the corridor overlooked by the laboratories does not respect the safety rules;
- second floor: the corridor of the southern classrooms does not meet safety rules here, too.

4.4.11. GYM: CHECK F.3

The check identifies the gym's occupancy. For this kind of space, rules exclusively define a minimum social distance of 2 m. Here, the gym is modelled within Revit software, and the algorithm is then applied. The script calculates the number of students by defining a grid with dimensions of 2 m x 2 m. By using the script, results are shown in the room schedule or the properties set of the selected room in Revit software.

5. RESULTS AND DISCUSSION

Code-checking processes can be applied to various fields of construction engineering. Therefore, a BIM model can be used for compliance checks with different standards. The strength is to carry out checks automatically or semi-automatically with tools providing assurance of high-quality results. Conversely, by adopting the traditional method based on 2D CAD drawings, checks are carried out manually and on a sample basis. The literature clearly shows that manual approaches for building compliance checking usually lead to inconsistencies. Several tools capable of carrying out code-checking processes now exist, among which "Solibri" software is one of the most used [25]. Tools like "Solibri" are very useful, especially with reference to standard checks. Actually, some of these tools have several customizing options for rules. However, such tools do not have scripting capability. On the other hand, Visual Programming Language tools couple scripting capability to a rather easy user interface. Therefore, these allow for carrying out infinite applications, including modelling processes and code-checking processes with highly customized rules.

This paper shows the control rules scripting process to verify the BIM model compliance with the guidelines for contrasting the COVID-19 spread. This approach has never been considered so far. Therefore, the application of code-checking processes allows school environments to be tested in order to verify compliance with guidelines for fighting the virus spread. Moreover, standards are constantly evolving. Therefore, the proposed approach allows modifying the algorithm according to the evolution of the standards. The methodology proposed in this paper makes it possible to verify on a real-time basis all the school environments by returning their conformity or non-conformity status with standards.

The proposed case study is limited to the evaluation of some typical environments of the Michelangelo public school in Bari, Italy. In fact, the present paper does not intend to express a judgment on the conformity of the school building considered. The goal of the analysis is to propose a code-checking methodology for compliance with standards for preventing the virus spread. The approach presented here can be replicated in all school contexts and applicable to all BIM models. However, BIM models must be previously prepared for this kind of activity. Indeed, the proposed workflow cannot avoid the BIM model preparation phase. Designers defining building models that will be used for rule checking or other kinds of simulations must arrange them so that the models provide the information needed in a well-defined agreed framework. Hence, the application of the algorithms in a VPL environment can be implemented only when the model has been set. In order to ensure the scripts work properly without errors, the BIM model must have been enriched with the right semantic information. Current BIM platforms default to a minimal set of properties and provide the capability of extending the set. Nevertheless, users can add parameters to each relevant object to produce a certain type of simulation.

The approach proposed here, unlike manual controls, allows simultaneously processing a huge amount of data and simultaneously testing various environments. The BIM-based approach can be error-free and makes evaluations much faster. The lack of errors and the actions timeliness are essential parameters in emergency conditions. Thus, the design and construction managers are able to carry out several simulations to evaluate the optimal condition even before hypothesizing invasive re-functionalization scenarios both for the buildings and the human capital. The advantage is to manage several variables and apply them to different application scenarios, and this becomes essential in an emergency situation with few resources and time available. Furthermore, the visualization capacity of the result offered by BIM allows for increasing the space management's control capacity.

The standards of COVID-19 prevention are constantly evolving, but the paper is limited to the period of drafting the study. The present study intends to provide a methodology and not a regulatory framework to be adopted. Therefore, according to the authors, the most representative Italian guidelines are taken into consideration here, also studying the type of controls to be applied to school buildings. Although several studies investigate code-checking processes [21–23], applying the BIM-VPL approach to the fight against Coronavirus has never been considered.

6. CONCLUSION

The World has had to contend with a huge pandemic for the past two years. The COVID-19 spread has resulted in a number of catastrophic scenarios. To date, there are millions of confirmed cases and hundreds of thousands of deaths. With reference to the school system, a series of guidelines have been issued to continue using school buildings safely. In fact, e-learning methods are considered less effective, especially in social terms. The presented BIM-based approach allows the simultaneous verification of different school environments with respect to pre-established safety rules. The literature highlights several potential benefits of using automation to support design compliance checking. In this case, the use of VPL tools for code-checking processes allows the real-time comparison among different layout scenarios, helping decision-makers opt for the safest scenario and guarantee the greatest room capacity. This leads to better exploitation of school buildings without displacing students and teachers to other buildings or opting for e-learning solutions. Moreover, it has recently been shown that e-learning negatively affects the social relationships between scholars and school staff.

The present paper is the first approach of a broader research study. Then, the proposed framework should be evolved in the future. Further research will consider a greater number of national and international standards, and different case studies will also be deemed to consider other existing guidelines. Furthermore, future research will focus on working environments in general and not just school ones. Also, future works will consider the different restrictions that will be deemed to prevent pandemics like this. Indeed, although the World appears to be coming out of the pandemic condition, this approach could be used to counter another wave or different types of pandemics.

Authors contribution

C. Cavalliere: data curation, formal analysis, investigation, project administration, software, supervision, validation, visualization, writing. G.R. Dell'Osso: conceptualization, formal analysis, investigation, project administration, supervision, validation, writing. F. Iannone: formal analysis, investigation, project administration, supervision, validation, writing. V. Milizia: conceptualization, data curation, investigation, software, writing.

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