A BIM-Based Approach to Assess COVID-19 Risk Management Regarding Indoor Air Ventilation and Pedestrian Dynamics

T. Delval, C. Sauvage, Q. Jullien, R. Viano, T. Diallo, B. Collignan, G. Picinbono

Abstract**—**In the context of the international spread of COVID-19, the Centre Scientifique et Technique du Bâtiment (CSTB) has led a joint research with the French government authorities Hauts-de-Seine department, to analyse the risk in school spaces according to their configuration, ventilation system and spatial segmentation strategy. This paper describes the main results of this joint research. A multidisciplinary team involving experts in indoor air quality/ventilation, pedestrian movements and IT domains was established to develop a COVID risk analysis tool based on Building Information Model. The work started with specific analysis on two pilot schools in order to provide for the local administration specifications to minimize the spread of the virus. Different recommendations were published to optimize/validate the use of ventilation systems and the strategy of student occupancy and student flow segmentation within the building. This COVID expertise has been digitized in order to manage a quick risk analysis on the entire building that could be used by the public administration through an easy user interface implemented in a free BIM Management software. One of the most interesting results is to enable a dynamic comparison of different ventilation system scenarios and space occupation strategy inside the BIM model. This concurrent engineering approach provides users with the optimal solution according to both ventilation and pedestrian flow expertise.

Keywords**—**BIM, knowledge management, system expert, risk management, indoor ventilation, pedestrian movement, integrated design

I. Introduction

As a major stakeholder of the management and operating maintenance of about 100 secondary schools, the Hauts-de-Seine department had to come up with solutions to help the operating teams of these schools to manage COVID risk. It did so by first providing them with decision making support and scientific data. Secondly, as the French government had set up new regulations to fight the spread of the virus, without any mean to assess its efficiency, the Department of Hauts-de-Seine decided to use BIM to allow its teams and the secondary schools operating teams to work jointly on the risk management.

First simulations were carried out on the basis of pilot college to define initial expert rules. These simulations are based on conventional floor plan and enable air renewal calculations in order to limit the spread of the virus in the air in different types of classroom. Other simulations based on flow management were carried out in order to limit the risk of congestion in classrooms corridors. Thanks to these analyses different recommendations have been published as the following: "Promote classes in rooms with mechanical ventilation (science rooms) or in rooms with a high air renewal capacity (possibility of opening large window areas)".

The idea of our research was to define digital rules to scan the data from the digital model in order to compare the risk to COVID-19 of pre-defined spaces, based on physical criteria. Regarding pedestrian analysis we used the time of congestion and the density of person per square meter in the corridors. Regarding airflow analysis we used the maximum exposure (full concentration of COVID-19 on time of study). With these digital rules issued from the simulations, we define a base of knowledge that we used on new configuration of spaces. The objective is to compare the configuration of the spaces and to apply (if it is possible) this knowledge to the new spaces. The model can be analysed very quickly and do not need simulation anymore. We are able to identify areas of risk, an exercise that could be particularly time consuming when analysing all layout of the building or simulating the entire building environment.

The paper will first present how the indoor air quality/ ventilation model has been used, for the COVID risk management, to estimate the virus indoor concentrations and the cumulative exposure to virus particles over time according to relevant parameters: building/room geometry, air tightness of the envelope, type of ventilation system ventilation schedule, and possible building configurations. The paper will then describe how the pedestrian dynamics models have been applied to the COVID Risk Management, based on cellular algorithms. The last part of the paper will explain how the use of BIM semantic in the IFC model has enabled us to build an integrated system on which different knowledge and expertise have been implemented.

II. Airflow Analysis for a COVID-19 Risk Management Assessment

Ventilation plays a key role in the air transmission of the SARS-CoV-2 virus inside buildings. Some studies highlighted the importance of ventilation to reduce the spread of the SARS-CoV-2 infection [1], [2]. Recently some guidelines for reducing the risk of airborne infection with COVID-19 recommended an

T. De. is Deputy Head of Division for development of digital uses with the Centre Scientifique et Technique du Bâtiment, 84 AV Jean Jaurès, 77420 Champs sur Marne, France (e-mail: Thibaut.delval@cstb.fr).

increase as much as reasonable the ventilation rate [3]. Then, to better understand and control the transfer of the SARS-CoV-2 particles inside buildings, it is required to develop risk assessment tools that consider the emission rate of the virus, the main building characteristics (building/room geometry, air tightness of the building envelope, type of ventilation system, ventilation schedule…). Such tools can help to find the best ventilations strategies that minimise the air transmission of SARS-CoV-2 inside buildings. This study presents the indoor air quality/ventilation model MATHIS-QAI that has been adapted for the COVID-19 risk management, to estimate the virus indoor concentrations and the cumulative exposure to virus particles over time for different ventilation strategies.

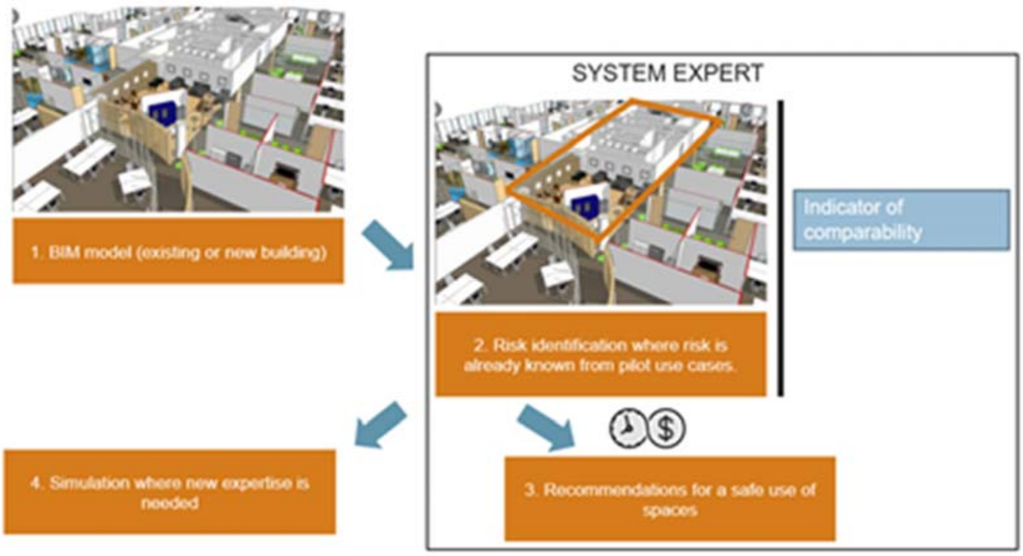


Fig. 1 COVID-19 Risk analysis strategy

Presentation of the Model

MATHIS-QAI is a software that predicts the Indoor Air Quality (IAQ) of buildings. It is an extension of the thermo-aeraulic, nodal model MATHIS (Modélisation de l'Aéraulique, de la Thermique, et de l'Humidité InstationnaireS d'un bâtiment) developed at CSTB [4]. The aerosol transfer model integrated in MATHIS-QAI has been adapted to study the transfer of SARS-CoV-2 particles inside buildings. This model currently considers the main aerosol transfer phenomena in indoor environments (penetration, convection, deposition, resuspension, filtration). In this study, the phenomena of penetration (concentration of SARS-CoV-2 outside the building is zero) and re-suspension of SARS-CoV-2 particles are not considered. Only the phenomena of convection of particles in the interior volume of a given zone and their deposition on the interior walls (floor, walls, ceiling) are considered. The transfer of SARS-CoV-2 particles in each zone of the building is governed by:

$$\frac{dY_{in,i}}{dt} = \sum_i \left(P_{x,i}\frac{\dot{Q}_{in,i}}{V}\right) Y_{out} + Y_{out}\left(\frac{\dot{Q}_N}{V}\right)(1-\eta_F) - \left(\frac{\dot{Q}_{out,i}}{V} + r_d + \lambda_a\right) Y_{in,i} + \text{CTRL1} \times \text{TRE} \times Y_{a,i} + \frac{1}{\rho^i}\,\text{CTRL2} \times \frac{Ev}{V} \quad (1)$$

where $Y_{in,i}$ is the fraction of SARS-CoV-2 particles in zone i [Copies/kg]; $Y_{a,i}$ is the fraction of SARS-CoV-2 particles on the floor [Copies/kg]; E_v is the emission rate of SARS-CoV-2 particles [Copies/s]; $Q_{in,i}$ is the supply airflow in the zone by the building envelope and ventilation components [m^3/s]; $Q_{out,i}$ is the exhaust airflow in the zone i [m^3/s]; V is the volume of the zone [m^3]; ρ^i is the density of air; CTRL2 is the controller of SARS-CoV-2 particles emission (if CTRL2 = 0, no virus emission, if CTRL2 = 1 the virus is emitted); r_d is the deposition rate of particles on the internal surfaces [s^{-1}]. Y_{out} the outside fraction of SARS-CoV-2 is equal to zero [Copies/kg]; $P_{x,i}$ the penetration factor in the zone i [-]; TRE the resuspension rate [s^{-1}]. η_F [−] the filtration of ventilation systems; CTRL1 the controller of resuspension. The fraction of SARS-CoV-2 $Y_{a,i}$ (Copies/kg) on the floor is:

$$Y_{a,i} = \frac{1}{\rho^i} C_{a,i} \frac{S_f}{V} \quad (2)$$

where S_f is the surface of the floor [m^2] and $C_{a,i}$ is the load of particles on the of zone i [Copies /m^2] and given by (4). Furthermore, given the lack of information on the SARS-CoV-2 lifespan, the virus deactivation rate λ_a [s^{-1}] has not been considered in this study. This implies a lifespan of the virus equal to that of the simulation time and is therefore a safe assumption by possible overestimating the amount of active virus load in the air. The deposition rate of SARS-CoV-2 particles is given as:

$$r_d = v_d \frac{S}{V} \quad (3)$$

where v_d is the deposition velocity [m/s] and S deposition surfaces [m^2]. The deposition velocity on the different walls (floor, walls, ceiling) is estimated with the Lai and Nazaroff model [5]. This model considers the influence of the diameter of the particles. The mass balance of SARS-CoV-2 on the floor of zone i is:

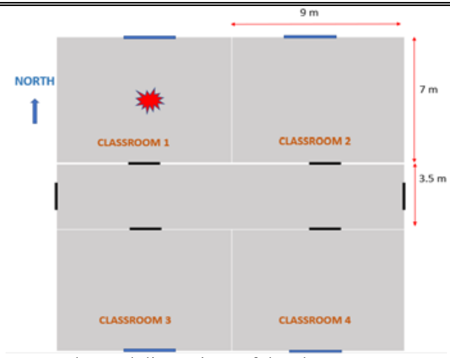
$$\frac{dC_{a,i}}{dt} = r_d \times C_{in,i} - CTRL1 \times TRE \times C_{a,i} \qquad (4)$$

where $C_{a,i}$ is the load of particles on the of zone i [Copies /m^2]. TRE is the resuspension rate [s^{-1}].

Model Inputs and Outputs

Two types of buildings have been studied (a school building and an office building). The results are presented for the school building only. The simulations have been performed with the time step of one hour for two periods (Winter, Mid-season) for Trappes Town in France and for five days (Monday to Friday). The main inputs of the model are summarized in Table I.

TABLE I
AIRFLOW SIMULATION INPUTS

Building configuration	 Plan and dimensions of the classrooms, the asymptomatic person is located in classroom1, the internal doors are closed with undercuts of 2 cm
Ventilation systems strategies	Scenario 1: building without ventilation system Q4Pa = 1.5 m^3/ (h.m²) / (Old building with window change) Scenario 2: building without ventilation system Q4Pa = 2.5 m^3/(h.m²) / (Old building without window change) Scenario 3: case 2 + opening windows 5 minutes per hour Scenario 4: Exhaust Mechanical ventilation (air inlets in the offices and the air outlet in the corridor), Exhaust airflow 1872 m^3/h. Scenario 5: case 4 + opening windows 5 minutes per hour Scenario 6: balanced ventilation (an air inlet and an air outlet in each room), Supply airflow by classroom = exhaust airflow by classroom 460 m^3/h Occupancy schedule: (8 a.m.-12 a.m / 2 p.m-6 p.m) / 30 students per classroom Ventilation schedule: 8 a.m-7 p.m
Virus Emission rate	The emission of SARS-CoV-2 particles by an asymptomatic person is estimated to be Ev = 1.06 10^{-2} Copies corresponding to the viral load emitted during respiration (based on current knowledge of the virus). For the different scenarios, infected people are considered asymptomatic and with no coughs or sneezes. These two modes of air exhalation (coughing and sneezing) modify the viral flow emitted in the air. It is considered that occupants showing symptoms will not be present in a classroom.

Outputs of the model: For each zone the cumulative air renewal rate ACH (h^{-1}), the virus concentration (RNA Copies/ m^3) and the cumulated exposure (RNA Copies) have been estimated. This cumulative exposure is defined as the quantity of inhaled virus in RNA "Copies" for a given period. It is assumed that the more a person is exposed to the virus, the more this person accumulates the viral load. The cumulative exposure corresponds to an indicator that allows to compare the different studied scenarios

III. RESULTS

Fig. 2 presents an example of results for two scenarios, scenario 1 with a building without ventilation system and scenario 4 with exhaust mechanical ventilation.

Indoor concentrations as well as cumulated exposures to SARS-CoV-2 particles decrease with increasing the air renewal rate. The air renewal rate is higher for the building with exhaust mechanical ventilation. Consequently, the concentrations are very lower for the scenario with mechanical ventilation (Concentration max: 1.6 Copies/m^3 vs 0.08 Copies/m^3). Cumulative exposures to SARS-CoV-2 particles increase over time. The cumulative exposure curves present some “plates” that correspond to the inoccupancy periods of classrooms between 6 p.m.-9 a.m. and 12 a.m.-2 p.m. while there is no emission of viral particles. Indoor concentrations and cumulative exposures to SARS-CoV-2 particles in classrooms 2, 3 and 4 are marginal compared to those in classroom 1 where the asymptomatic person is located.

Cumulative exposure: Fig. 3 shows the cumulative exposure for the different ventilation scenarios for winter and mid-season periods. For scenarios without a ventilation system (Sc1, Sc2, Sc3), the exposure is significantly lower in winter than in summer. In fact, the air renewal rate is greater in winter because of the greater natural forces during this period (stack effect and the effect of the wind on the building envelope). For mechanical ventilation, the influence of the season is marginal because of the low part of natural forces on the air renewal rate. Mechanical ventilation scenarios have almost the same effectiveness in lowering exposure to SARS-CoV-2 particles.

The main conclusion of the study is summarized below.

– For classrooms without a ventilation system:
- Exposure to SARS-CoV-2 particles is greater in old school buildings with a window change, compared to that in old school buildings without window changes which are less airtight, and which thus have a slightly greater renewal of air through air leaks.
- Opening windows for 5 minutes every hour during classroom occupancy significantly reduces the cumulative exposure to SARS-CoV-2 and this decrease is greater in winter (69.3% in winter compared to 42% in mid-season).

– For classrooms equipped with a mechanical ventilation system:
- The efficiency of mechanical ventilation (ensuring the airflow recommended rates) significantly reduces exposure to virus particles compared to school buildings without a ventilation system (from 67.5 to 92% reduction). Thus, mechanizing ventilation in school buildings would significantly reduce the cumulative exposure to SARS-CoV-2.
- The opening of windows for 5 minutes every hour during the occupancy of the rooms with the exhaust mechanical

ventilation has little influence on the exposure (1.7% decrease in winter against 1.4% in mid-season).

- The three studied mechanical ventilation strategies significantly lower exposure to SARS-CoV-2 particles compared to scenarios without a ventilation system. Also, the balanced mechanical ventilation system appears to be the most effective strategy for reducing exposure to SARS-CoV-2 and lowering heating energy-consumption due to air renewal.
- The extension of the ventilation operating hours from (8 a.m -7 p.m.) to (6 a.m-9 p.m) does not reduce the cumulative exposure in classrooms.

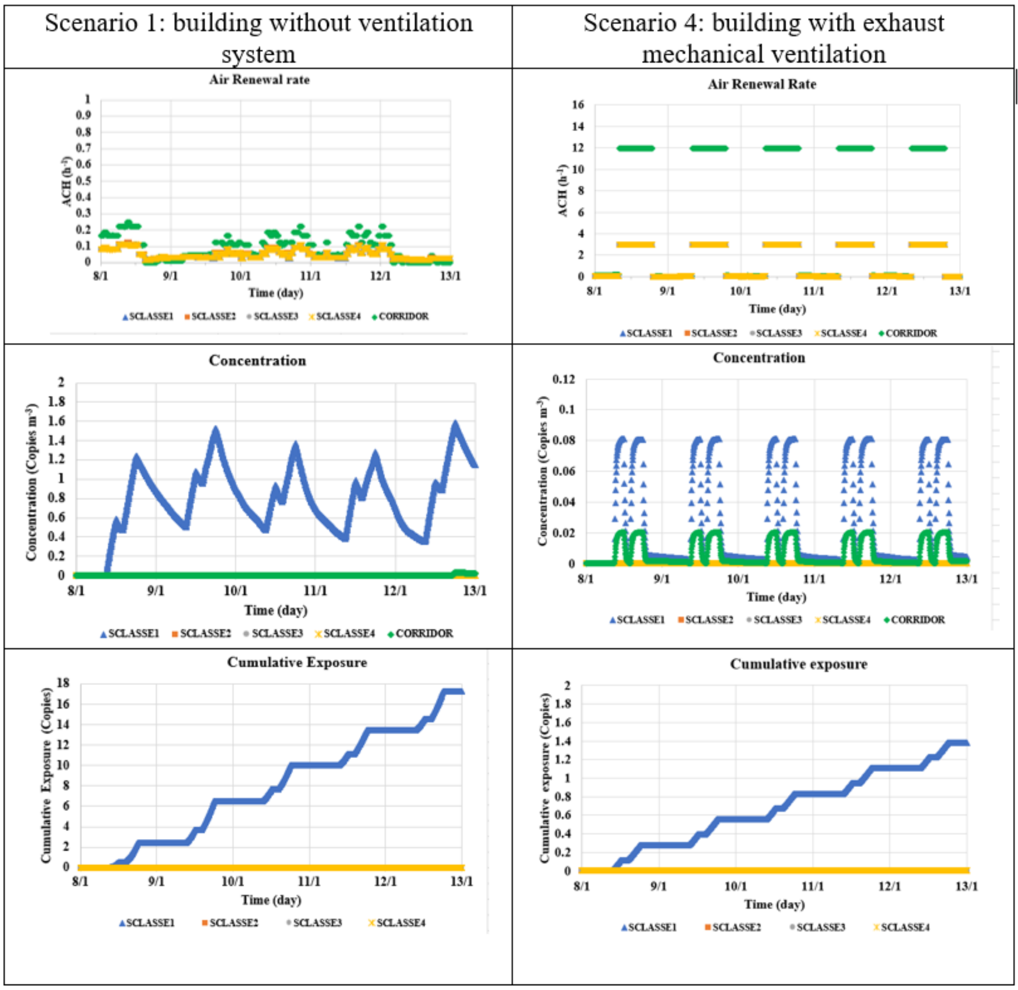


Fig. 2 Evolution of the air renewal rate, concentration and the cumulated exposure

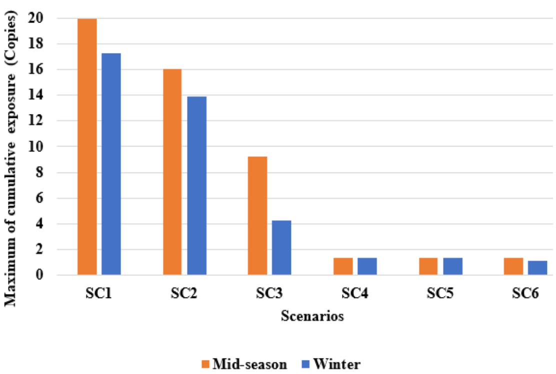


Fig. 3 Maximum concentration of the cumulative exposure

Abacus for the expert system: The estimated cumulative exposure for different ventilation scenarios and different classrooms have been organised in an abacus that is linked to the "system expert". In order to discretise the different cumulative exposures, a colour index has been suggested hypothetically.

IV. Pedestrian Dynamic Analysis for a COVID-19 Risk Management Assessment

Background and Scope

Methods used to describe pedestrian movement within buildings have been mostly developed in the field of fire safety to ensure safe evacuation. Some of these methods include panic behaviour [6] and allow to determine population densities in clustered areas during a movement phase (such as the exit of rooms). Associated to the progress of numerical capabilities, several software have been developed such as buildingEXODUS [7], Pathfinder [8] or EVAC [9]. These advanced modelling tools generally represent each individual separately with specific features (such as walking speed, individual behaviour in front of conflict, knowledge of the pathway inside the building) [10]. The microscopic models describe the interactions between people and differences of behaviours. However, some of these tools are black boxes, time-consuming because they require meshing the building and require several entry data [11]. In order to implement a rapid assessment into a digital building model, it was necessary to achieve a simplified model to describe pedestrian dynamics in the high-density zones (such as staircase and corridor exists). The model was based on simplified macroscopic analytical formulations from historical approaches such as Togawa [12] or Predtechenskii Milinskii [13] while also being more representative (by taking indirectly into account the interaction between people [14], [15]).

TYPOLOGIE	SAISON	SCENARIO DE VENTILATION	PORTES	CONTAMINANT	LOCAL	EXPOSITION CUMULEE MAX	COMMENTAIRE
ECOLE	HIVER	SC1	PF	NC1_CL1	CL1	17.27	
ECOLE	HIVER	SC2	PF	NC1_CL1	CL1	13.89	
ECOLE	HIVER	SC3	PF	NC1_CL1	CL1	4.25	
ECOLE	HIVER	SC4	PF	NC1_CL1	CL1	1.38	
ECOLE	HIVER	SC5	PF	NC1_CL1	CL1	1.36	
ECOLE	HIVER	SC6	PF	NC1_CL1	CL1	1.16	
ECOLE	HIVER	SC1	PF	NC1_CL1	CL2	2.00589E-10	
ECOLE	HIVER	SC2	PF	NC1_CL1	CL2	2.90283E-09	
ECOLE	HIVER	SC3	PF	NC1_CL1	CL2	4.28104E-08	
ECOLE	HIVER	SC4	PF	NC1_CL1	CL2	1.20393E-05	
ECOLE	HIVER	SC5	PF	NC1_CL1	CL2	6.61511E-11	
ECOLE	HIVER	SC6	PF	NC1_CL1	CL2	5.46929E-06	
ECOLE	HIVER	SC1	PF	NC1_CL1	CL3	6.91727E-05	
ECOLE	HIVER	SC2	PF	NC1_CL1	CL3	0.000156879	
ECOLE	HIVER	SC3	PF	NC1_CL1	CL3	5.64357E-05	
ECOLE	HIVER	SC4	PF	NC1_CL1	CL3	2.97038E-09	
ECOLE	HIVER	SC5	PF	NC1_CL1	CL3	1.07124E-06	
ECOLE	HIVER	SC6	PF	NC1_CL1	CL3	1.3783E-09	
ECOLE	HIVER	SC1	PF	NC1_CL1	CL4	6.91727E-05	
ECOLE	HIVER	SC2	PF	NC1_CL1	CL4	0.000156879	
ECOLE	HIVER	SC3	PF	NC1_CL1	CL4	5.64357E-05	
ECOLE	HIVER	SC4	PF	NC1_CL1	CL4	2.97038E-09	
ECOLE	HIVER	SC5	PF	NC1_CL1	CL4	1.07124E-06	
ECOLE	HIVER	SC6	PF	NC1_CL1	CL4	1.3783E-09	
ECOLE	HIVER	SN_IND	PF	NC1_CL1	SN	IND	INDETERMINE
ECOLE	HIVER	CLR_IND	PF	NC1_CL1	CLR	IND	INDETERMINE

Color Index	Maximum Cumulative Exposure (Copies)
	≤ 1
	]1-3]
	]3-5]
	]5-6]
	> 6

Fig. 4 System Expert Abacus for Airflow analysis

Since the model is simplified with limited entry data, its scope of application is narrower than advanced software. A density zone is defined as an area at the end of a corridor and before a staircase. The model outputs the evolution of the number of people within this density zone (typically 4 m²) after a transient situation (such as the simultaneous exits of all the rooms in the corridor). This zone was selected because it represents the space where congestion is most likely to occur. The choice of the density zone has little influence on a comparative study to evaluate the efficiency of the different strategies between themselves. To run the model, each room (initially containing N_i occupants) is evacuated with pedestrians walking towards a given staircase (Fig. 5). This implies having one-direction staircases as was observed in several public buildings during the pandemic. The user needs to declare on 'pool of rooms' associated to an identified staircase.

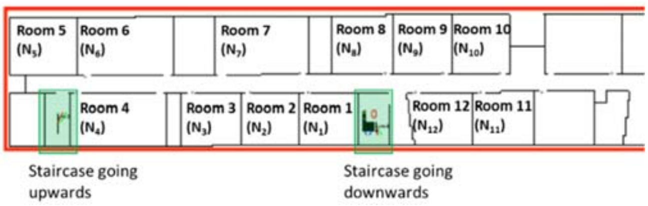


Fig. 5 Example of a building configuration with a pool of rooms and a staircase associated to a density zone

Presentation of the Model and Entry Data

The corridor and adjacent rooms are described in a 1D problem where each room (i) presents an occupancy of N_i and the door of each room is separated from the density zone by a distance L_i (Fig. 6). The walking speed depends on the environment (related to the density of occupants as described hereafter) but is initially the same for each induvial. Building pedestrians are modelled as points occupying a space that is not their own. The program allows two individuals to be at the same position without any allocation conflict.

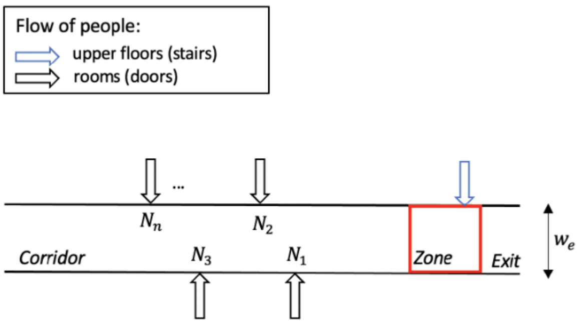


Fig. 6 Simplified representation of a corridor

Social interactions are taken into account in two different ways: first, with the speed versus density law in a traffic space (density zone) and secondly, via a conflict coefficient at the exit door. The density in the density zone is limited by 4 pers/m². The SFPE Handbook [16] indicates that the speed of a person in a congested space at 4 pers/m² is equal to zero. Room exits are conservatively assumed to be simultaneous in order to increase the risk of congestion. Individuals are positioned in a row with a distance of half a meter in between each person. The speed model used in this method is based on the one from the fifth edition of the SFPE Handbook [16] (5):

$$v(D) = v_{\infty}(1 - a.D) \quad (5)$$

where v_{∞} is the uncongested speed, a is a coefficient of friction and D is the density of people. This description represents the decrease of walking speed in congested areas presenting a high density.

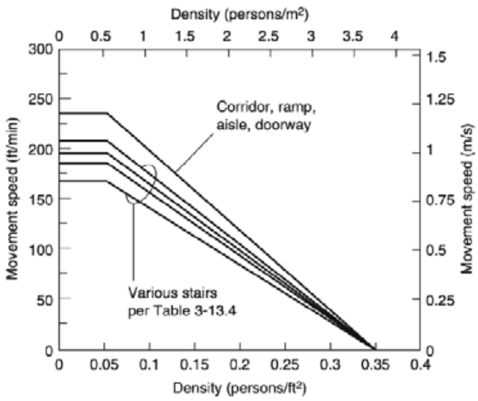


Fig. 7 Speed versus density law from the SFPE Handbook

At the microscopic level, each individual is described by his position in the corridor x_i, his speed v_i and an indicator function associated with the density zone $\mathbb{1}_{zone}$. This function determines the use of the velocity-density law. The velocity equation is expressed for the i[th] individual at the j[th] time (6):

$$\frac{dx_j^i(t)}{dt} = v_j^i(x,t) = v_{\infty}\left(1 - a\frac{N_j(x)}{S_{zone)}}\right) \quad (6)$$

The equations are solved using finite differences implemented into a Python code. At each time-step the number of people inside the density zone is quantified by associated a presence function $\mathbb{1}_{zone}$ to each individual where I is the set of individuals (7):

$$N(x) = \sum_{i\epsilon I} \mathbb{1}_{zone,i}\,(x_j^i) \quad (7)$$

The variation of the number of individuals inside the density zone is obtained by conservation of the number of occupants. The density zone is considered as a fluid reservoir with an input flow rate Q_{in} and an output flow rate Q_{out} (8):

$$\frac{dN(t)}{dt} = Q_{in}(t) - Q_{out}(t) \quad (8)$$

N is the number of people in the density zone. The input flow rate depends of the initial distribution of individuals in the rooms of the current and upper floors and is associated to the walking speed. The output flow rate Q_{out} depends linearly with the width of the exit as expressed in (9):

$$Q_{out} = \alpha.w_e \quad (9)$$

The coefficient α takes into account the effects of conflict at the exit. Through a parametric analysis, alpha was determined empirically by using a microscopic model (buildingEXODUS) where each person is modelled by an independent particle. This allows to determine the exit flow rate taking into account the interaction between each particle for different widths w_e. Though several simulations, it was determined that α was close to 0.78 prs/s/m.

If the number of occupants is higher that a given threshold, the density saturates at a maximal level inside the zone (usually 4 pers./m²). The critical population, N* corresponding to this saturation can be obtained by conservation of the number of people (10):

$$N^* = N_{max} + t_{max}.Q_{out} \quad (10)$$

t_{max} is the time at which the saturation of the congestion zone occurs (when $N = N_{max}$). The critical population is given by the sum of the maximum population in the density zone and the number of people who had time to leave the density zone while it was filling up. This allows to determine if the saturation plateau is reached and the duration of this plateau through (10).

Analysis of the Output

The model outputs the number of people inside the density zone versus time. Fig. 8 presents the evolution predicted by this simplified method in blue in comparison to the one from the advanced software (buildingEXODUS) based on cellular automate (allowing representation of the position of the pedestrians). Predictions from both software appear to be similar. Although the methods yield similar predictions, the advanced software nevertheless presents a less restricted scope of application than the simplified method (that was developed mainly to be implemented in the digital building model).

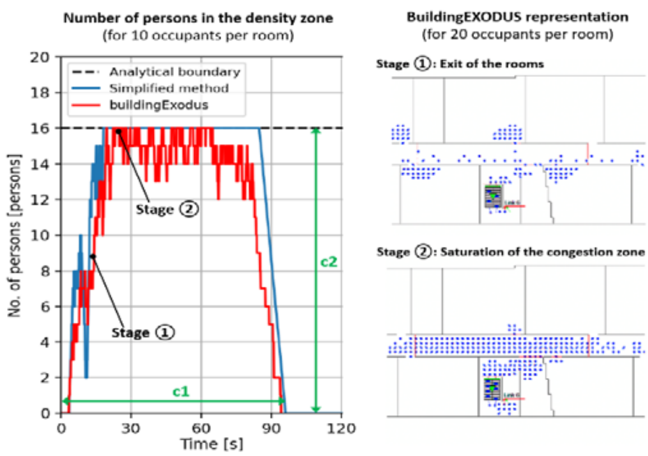


Fig. 8 Example of a building configuration with a pool of rooms and staircase containing the density zone

The curve presents an initial increase corresponding to the exit of the classes and the progressive filling of the density zone (stage ①). At an occupation of 16 people, a plateau is formed by saturation since the maximal density of 4 pers./m² has been reached (stage ②). Changing the occupation strategy in the building model (such as reducing the number of students per class or reducing the number of classes and separating the occupied rooms in the corridor) allows to obtain different curves. The efficiency of the different strategies is assessed by quantifying two criteria. The first criterion (c_1) is the duration during which the density zone is occupied. The second criterion (c_2) is the amplitude of the occupation (corresponding to N_{max}). Depending on safety thresholds associated to the c_1 and c_2 values, a risk level can be associated to the studied area of the building regarding human contact. This risk level is attributed to the pool of rooms linked to a staircase (associated with the density zone) which are coloured (from green to red) depending on the risk level on the digital building model.

V. Analysis Implementation on BIM Model

Since the beginning of the COVID-19 pandemic, some universities or software vendors have developed specific application to address the virus contamination into public buildings. For example, "Open BIM COVID-19" by CYPE allows, from the BIM model of a building, to specify the space planning of the building and check that each room respects physicals distancing regulations. In [17], the authors present a methodology and software to study the parts of a building where the density of people increases to much the risk of contamination. In [18], it is demonstrated that the right use of BIM CAD software can ease the design of COVID-19 optimized MEP systems.

Our approach focuses on multi-physique simulation, allowing concurrent engineering optimization of a building in order to lower the risk of COVID-19 contamination in high school buildings.

In this part, we will explain how the numerical simulation presented in the two first part of the article has been connected to a BIM system, allowing to run different analysis directly from a IFC model of a high school.

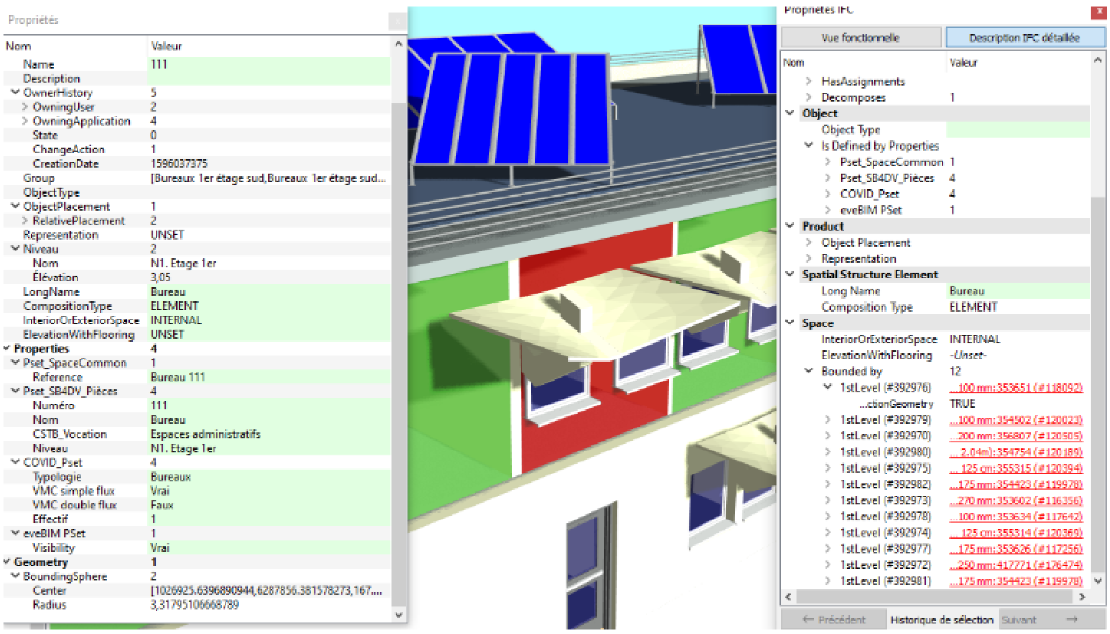


Fig. 9 View of IFC-Covid Model in eveBIM

BIM/SIM Integration

The concept of BIM is to build a virtual representation of a building, containing enough semantical, relational, and descriptive information to perform a certain set of analysis, at a given phase of a construction project (design, construction, exploitation, …). All this information will be gathered in a BIM model, and all analysis will be run from this common data. The system we present here is based on the OpenBIM format IFC[1]. IFC format is the exchange standard for construction industry. It allows to describe all information of a building: the components (walls, slabs, beams, doors, windows, …), the topology (rooms, storeys, zones, …); each element holds properties, material, and relations with other elements.

The BIM-Simulation integration can be split into two parts:

- BIM2SIM: The first step is to analyse and extract information from the BIM in order to build the simulation model. Depending on the complexity of the numerical simulation, this step can simply consist of retreating properties and quantities or implying some advanced geometry/topology interpretation. The main advantage of the approach is replicability: once the BIM2SIM system is implement, one can run simulation automatically from any new BIM model.
- SIM2BIM: Once the numerical simulation is done, it can be very interesting push some of the results back into the BIM model. This way you can use the BIM model to give

[1] Industry Foundation Classes

a visual representation of the result, or the simulation results could be used for further task or analysis.

Following the BIM/SIM integration pattern described in Fig. 9, our system is based on the free BIM management software developed by CSTB: eveBIM®.

Data Completion

One of the most important part in BIM/SIM integration is the quality and completeness of information in the BIM model. In order to be able to extract automatically information one needs to run the simulation, data in the BIM model must be carefully planned and prepared. This can be achieved in three main steps:

1. Digitalisation specification: This first step consists of the definition of very precise specifications of the data that have to be included in the model, while trying to keep it as simple as possible (too much information can be a drawback). Following this document, the designer will use CAD software to produce all information specified. The specification document describes what entities should be modelled (wall, slab, beams, rooms, …), how to name them, and what properties they should contain.
2. Some information may be very difficult to define in a CAD software. In this case, another software can be used to complete the BIM model. For example, to run ventilation or flow simulation, we need to define zones (groups of rooms). This task in done directly in eveBIM® software thank to a dedicated "Zoning plugin".

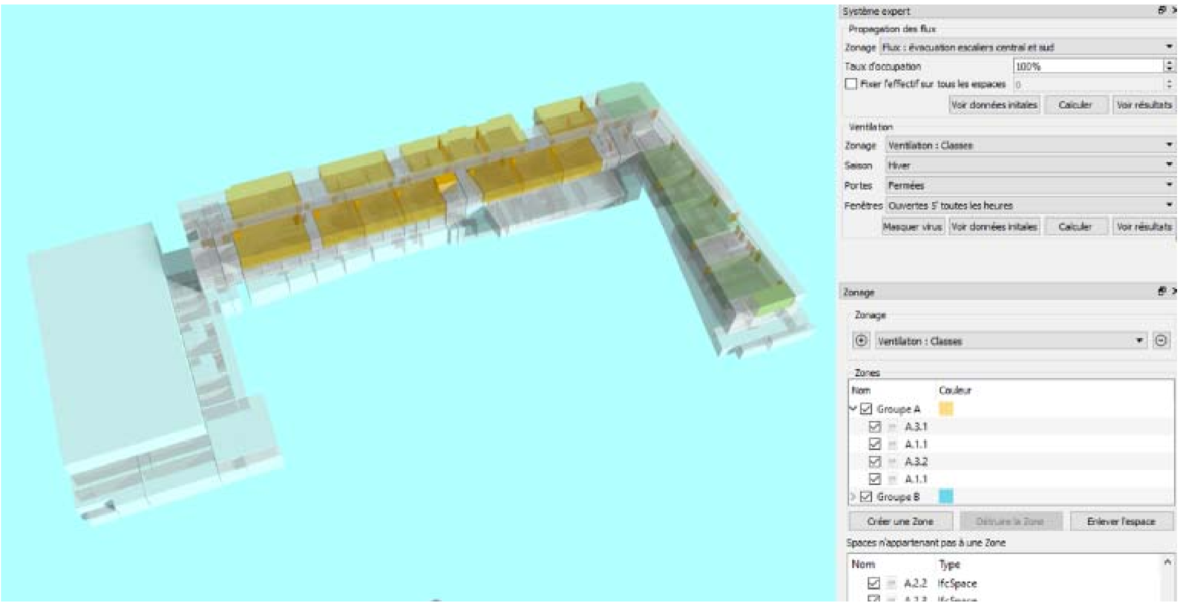


Fig. 10 COVID-19 Group System and IHM

3. Finally, simulation models may require some information that if not directly available in the BIM model, but has to be computed. For example, the flow simulation needs the distance between each class door to the closest exit. In this case, a specific algorithm has been implemented to compute this information "on demand" and included into eveBIM® software (we call it a "prefigurator"). This calculation requires an expert use of the Spaces of the model and their Boundaries the surrounding building elements.

COVID Expertise

A "COVID Expertise" plugin has been integrated into eveBIM® software. Based on information included in, or computed from, BIM model, this plugin allows to perform a ventilation risk analysis and an Evacuation Flow risk analysis. Both analyses are based on the scientific result presented in the first part of this article.

Ventilation Risk Analysis

From the simulation results presented in Section II, a set of abacuses has been built, expressing risk analysis results according to deferent values of input parameters: geometry of the rooms, type of windows, type of ventilation systems, ventilation strategy. According to the parameter values retrieved from the BIM, the system finds the best matching results. The user can also modify some parameters directly from the user interface in order to compare different strategies trying to lower the risk.

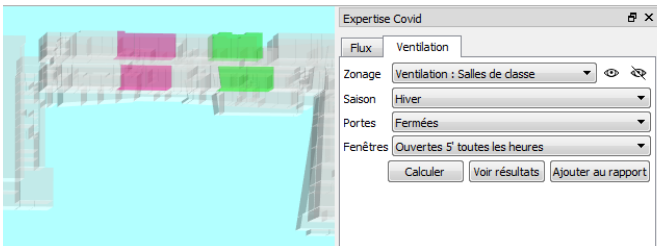


Fig. 11 Ventilation Risk analysis User Interface

Once computed, the simulation results are stored into the BIM model and graphically rendered as colour maps.

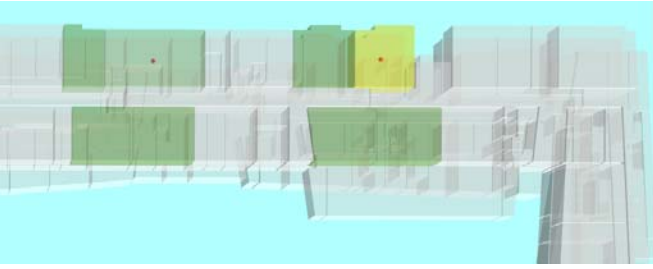


Fig. 12 Ventilation risk analysis results

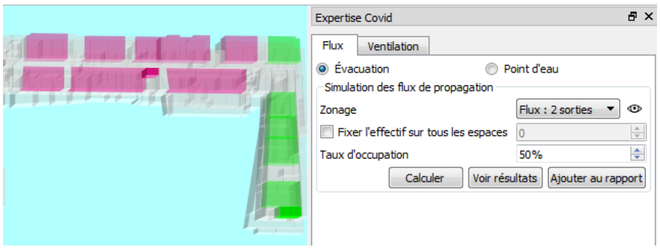


Fig. 13 Evacuation Flow risk analysis User Interface

Evacuation Flow Risk Analysis

For the simulation results presented in Section III, another strategy has been chosen: A simplified algorithm to compute the risk of congestion due to students outing their classroom has been created and implemented. This algorithm is directly called from the "COVID Expertise" plugin and fed with the input parameters redden from the BIM model or computed from it (like the distance between classroom doors and closest exit). A dedicated user interface allows the user to choose between several scenarios and adapt some parameters to find the optimum solution.

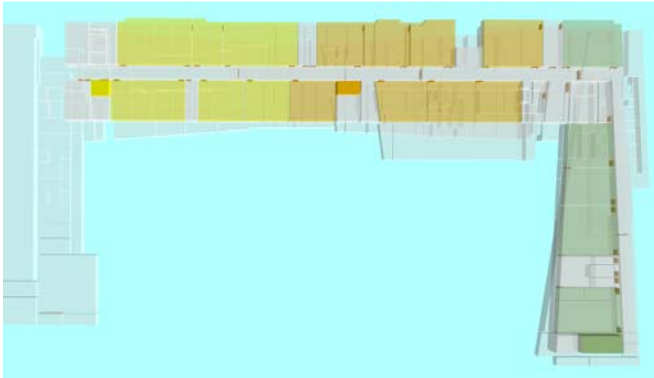
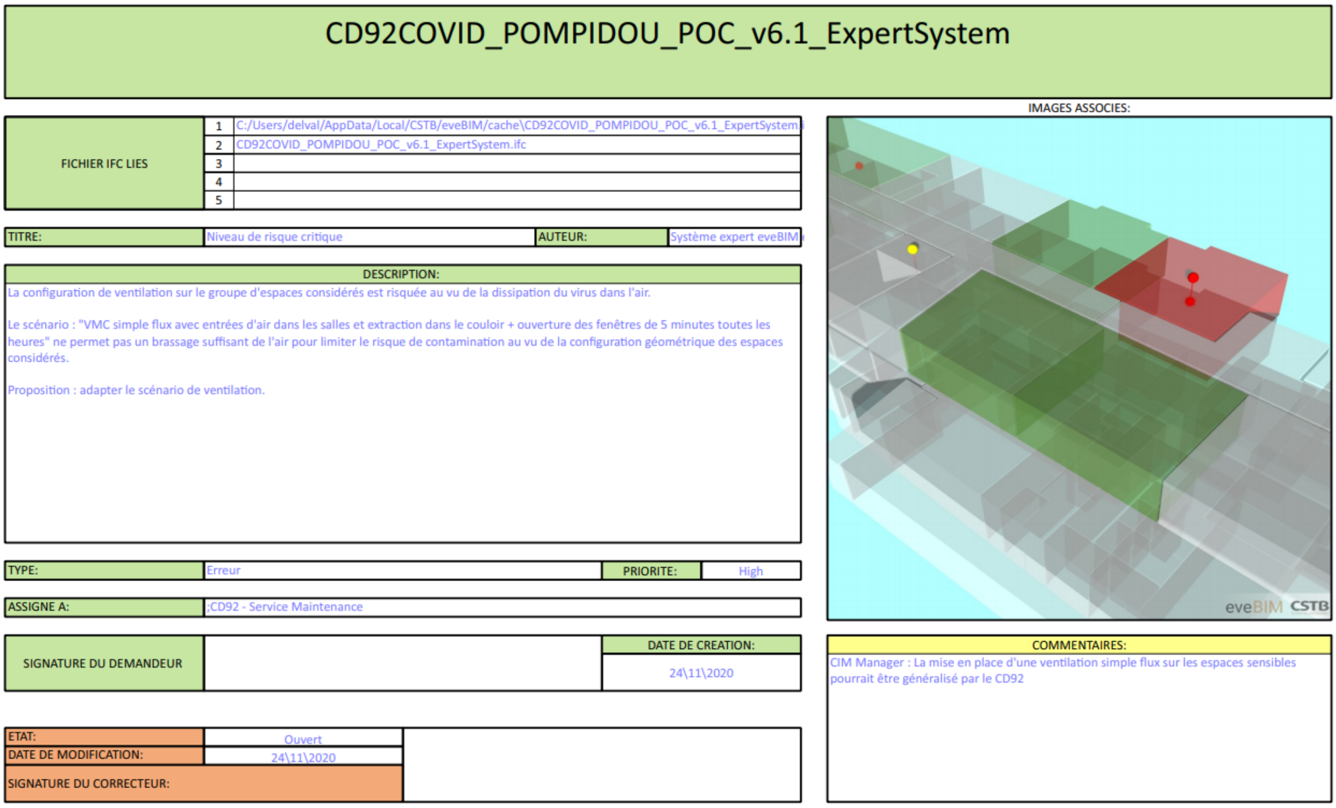


Fig. 14 Evacuation Flow risk analysis results



CD92COVID_POMPIDOU_POC_v6.1_ExpertSystem

FICHIER IFC LIES		
	1	C:/Users/delval/AppData/Local/CSTB/eveBIM/cache\CD92COVID_POMPIDOU_POC_v6.1_ExpertSystem
	2	CD92COVID_POMPIDOU_POC_v6.1_ExpertSystem.ifc
	3	
	4	
	5	

TITRE:	Niveau de risque critique	AUTEUR:	Système expert eveBIM

DESCRIPTION:

La configuration de ventilation sur le groupe d'espaces considérés est risquée au vu de la dissipation du virus dans l'air.

Le scénario : "VMC simple flux avec entrées d'air dans les salles et extraction dans le couloir + ouverture des fenêtres de 5 minutes toutes les heures" ne permet pas un brassage suffisant de l'air pour limiter le risque de contamination au vu de la configuration géométrique des espaces considérés.

Proposition : adapter le scénario de ventilation.

TYPE:	Erreur	PRIORITE:	High
ASSIGNE A:	;CD92 - Service Maintenance		

SIGNATURE DU DEMANDEUR		DATE DE CREATION: 24\11\2020

ETAT:	Ouvert
DATE DE MODIFICATION:	24\11\2020
SIGNATURE DU CORRECTEUR:	

IMAGES ASSOCIES:

eveBIM CSTB

COMMENTAIRES:

CIM Manager : La mise en place d'une ventilation simple flux sur les espaces sensibles pourrait être généralisé par le CD92

Fig. 15 Covid Risk BCF annotation

Results of the simulation are stored in the BIM model and can be displayed as colours corresponding to the different level of risk identified. On the example below the risks of congestion is considered as "moderate" on the East Wing but "weak" on the West Wing. An application to this result could be to define different cluster or to decrease occupancy of one of the rooms and to launch the analysis again.

Reports Extraction

The OPEN BIM approach has been also implemented in the result communication strategy. Each result including colorization, space ID, scenario of risk is extracted through an annotation in a BCF[2] format. The result and the link with the IFC object can thus be integrated into any type of modelling or visualising tool. The challenge here is to easily communicate the results to the administrative department of the relevant school, who may be unfamiliar with the BIM. Another application of the extracted results is to help design offices to adapt the design of buildings through the communicated BIM model connected to the Covid Analyses Annotation.

VI. Future Works

Toward a System Expert

The system developed so far is based on pre-defined rules analysis coming out of specific simulation use cases. One of the main results is to allow a dialogue between different disciplines (Information Technology, Air Quality, pedestrian movement). The system is open to the absorption of new contamination scenarios and allow analyses on other types of buildings. New simulation can be carried out to integrate new results in the analysis. The challenge of our future research is to create a formalization of the rules allowing the system itself to enrich its knowledge.

Covid Risk Management Applied to Space Planning

Our research is based on a static indicator of the level of risk and does not take into account the way spaces are occupied in reality. However, many building administrators have established allocation policies in order to manage spaces.

The new vision of BIM GEM allows applications for a dynamic space allocation management tools that could be linked to the risk analysis. It would be possible to adapt the flow management or the monitoring of ventilation systems according to a day-to-day analysis of risk and occupancy.

Other Applications: e.g., Temporary Water Supplies

Other ongoing research aims to use the results of the Covid expertise to set up temporary water supplies in scholar building. These temporary water supplies could be set up depending on the proximity of water systems and the risk of congestion through our Covid Analysis Approach.

References

[1] Buonanno, G., Stabile L. and Morawska L. (2020). "Estimation of airborne viral emission: quanta emission rate of SARS-CoV-2 for infection risk assessment." Environment International: 105794.

[2] Dai, H., Zhao, B. Association of the infection probability of COVID-19 with ventilation rates in confined spaces. Build. Simul. 13, 1321–1327 (2020).

[3] RHEVA, 2020. COVID-19 guidance, 2020.

[4] F. Demouge, 2018. MATHIS - Mathis: guide technique. (Rapport de recherche) CSTB - Centre Scientifique et Technique du Bâtiment. 2018. ffhal-01529613v3f

[5] Lai, A.C.K., Nazaroff, W.W., 2000. Modelling indoor particle deposition from turbulent flow onto smooth surfaces. Journal of Aerosol Science31, 463–476

[6] Clarke. *Panic: Myth or Reality?* Vol. vol I, n°3. 2002.

[7] Galea Filippidis Blackshields Lawrence Gwynne and Cooney. *buildingEXODUS v6.3 user's guide*. 2017.

[8] *Pathfinder user's guide*. url: https://www.thunderheadeng.com/pathfinder/.

[9] Korhonen. *FDS and Evac technical reference and user's guide*. Ed. by VTT Working Papers. 2018.

[10] Gwynne Galea Owen Lawrence and Filippidis. "A review of the methodologies used in the computer simulation of evacuation from the built environment". In: *Building and Environment* 34 (1999), pp. 741 – 749.

[11] Jullien Dréan Wyzgolik Zang Ntoung Blouin Kabalan Gwynne Ganiyu Collin Pianet Dong Bourlet Trévisan Faure Maury Pinsard Hourqueig Nejjar and Paillat. "Evacuation modelling – application to an office building using several simulation tools". In: *Fire and Evacuation Modeling, Technical Conference FEMTC* (2020).

[12] Togawa. "Study on fire escapes based on the observation of multitude currents". In: *Building Research Institute, Ministry of Construction of Japan* (1963).

[13] Predtechenskii and Milinskii. "Planning for foot traffic in buildings". In: *Amerind Publishing Co. Pvt. Ltd, New Delhi* (1971).

[14] Li Zhang Tang and Hu. "A minor modification in the model for describing congestion and recovery along evacuation paths". In: *Land Use Policy* (2015), pp. 751 –758. issn: 0264-8377.

[15] Thompson and Marchant. "A computer model for the evacuation of large building populations". In: *Fire Safety Journal* (2017), pp. 131 –148.

[16] Hurley. *SFPE Handbook of Fire Protection Engineering*. Ed. by Springer. Vol. 5th Edition. 2015, pp. 154 –164.

[17] Rubén Muñoz Pavón, Antonio A. Arcos Alvarez, Marcos García Alberti. « Possibilities of BIM-FM for the Management of COVID in Public Buildings". November 2020 Sustainability 12(23):9974

[18] Nazirul Fariq. Utilisation Of BIM for MEP Engineering Practice During Covid-19 Outbreak. August 2020 - Conference: 8th International Graduate Conference on Engineering, Science and Humanities (IGCESH) 2020 - At: Johor, Malaysia.

[2] BIM Collaboration Format