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How distant? An experimental analysis of students’ COVID-19 exposure and physical distancing in university buildings

A. Bartolucci a,*, A. Templeton b, G. Bernardini c

a Institute of Security and Global Affairs (ISGA), Leiden University, The Hague, the Netherlands
b Department of Psychology, The University of Edinburgh, Edinburgh, Scotland, United Kingdom
c Department of Construction, Civil Engineering and Architecture (DICEA), Università Politecnica delle Marche, Ancona, Italy

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ABSTRACT

Closed university buildings proved to be one of the main hot spots for virus transmission during pandemics. As shown during the COVID-19 pandemic, physical distancing is one of the most effective measures to limit such transmission. As universities prepare to manage in-class activities, students’ adherence to physical distancing requirements is a priority topic. Unfortunately, while physical distancing in classrooms can be easily managed, the movement of students inside common spaces can pose high risk of close proximity.

This paper provides an experimental analysis of unidirectional student movement inside a case-study university building to investigate how physical distancing requirements impact student movement and grouping behaviour.

Results show general adherence with the minimum required physical distancing guidance, but spaces such as corridors pose higher risk of exposure than doorways. Doorway width, in combination with group behaviour, affect the students’ capacity to keep the recommended physical distance. Furthermore, questionnaire results show that students report higher perceived vulnerability while moving along corridors. Evidence-based results can support decision-makers in understanding individuals’ exposure to COVID-19 in universities and researchers in developing behavioural models in preparation of future outbreaks and pandemics.

1. Introduction

In response to the COVID-19 pandemic, national and local governments have adopted a variety of measures to control or reduce the spread of the virus [1,2]. Such measures are mainly aimed at reducing physical contact among persons, reducing population mingling, and imposing the separation of citizens to ensure that, if they become ill or carry the virus, they will not transmit it to others [3]. Curfews, lockdowns, and closure of places where people gather in smaller or large numbers – including cancelling small and large gatherings (e.g., closures of shops, restaurants, shops) - occurred for an extended period. Additional measures included mandatory home working, physical distancing in public transport, and closure of educational institutions [4,5]. As consequence, schools, including universities, across the world have cancelled or reduced in-class activities and moved lectures and educational activities from face-to-face to online using alternative teaching activities such as online education, remote learning, or blended learning with a mix of the two [6]. Efforts to contain COVID-19 resulted in 107 countries implementing national school closures by March 18, 2020 [7] which impacted over 87% of the world’s student population [8].

* Corresponding author.
E-mail addresses: a.bartolucci@fgga.leidenuniv.nl, and.bart.olucci@gmail.com (A. Bartolucci).

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As educational institutions and universities decide to provide in class activity or to adopt a blended education (in-class and online learning), administrators need to find the best solution to avoid virus transmission to protect students, faculty, staff, and administrators. As already highlighted by Romero and colleagues (2020), one of the main priorities for schools is minimizing all aspects of COVID-19 exposure. The Center for Disease Control and Prevention (CDC) created guidance for Institutions of Higher Education providing risk assessment and implementing several strategies to encourage behaviors that reduce the spread of COVID-19.1

One of the most effective measures to prevent the spread of the disease is adopting physical distancing measures between people and reducing the number of times people come into close contact with each other [3,9–11]. This kind of strategy is also generally implemented to limit the effects of other respiratory viruses in closed environments [5,12]; N [13].

The physical distance between two individuals can influence their movement and use of building spaces both under normal and emergency conditions. In such situations, people may wait for other people to move and coordinate as a group to stay together. Two possible reasons for close proximity among group members are the group attraction phenomena [14], or having a social identity with those in the group (i.e. seeing others as fellow group members, see Ref. [15]. Research based in the social identity approach [16] poses that people exhibit higher coordination with those in their group and tend to seek being close to one another. For example, group members walk more closely together with people they perceive as being in their group compared to those not in their group [17], and will move more closely to one another to stay together when another group is present [18]. Moreover, previous research found that seeing others in the crowd as group members predicted being in a more central, denser location in the crowd [19]. Similarly, when given the choice to set up seating arrangements, people prefer to be seated closer to those they perceived to be in their group, compared with others outside their group or whose group membership they do not know [20].

However, the impact of group relations on physical distancing has not been tested during the COVID-19 pandemic when people are required to be physically distant to avoid putting others at risk. Previous literature from social psychology suggests that people are more likely to provide support to people in their group [21]. In the context of COVID-19, this could mean that group members are motivated to maintain correct physical distance to keep one another safe.

Keeping physical distance can increase the length of time taken to reach a destination because of physical constraints in closed environments like corridors, stairs and at doors [22,23]. University buildings represent one of the most relevant scenarios in the educational context due to the potential high number of daily and contemporary users, the frequency in users’ movements depending on the times of lessons and other teaching and learning activities (e.g. laboratories, libraries), as well as prolonged opening times [24]. Re-thinking the way students and staff use spaces in buildings and how they interact essentially means creating safety distance protocols and guidelines to be applied depending on the building features (i.e. the layout) that are typically designed to achieve minimal physical distance [22]. Such features include corridors, as well as access to rooms and elevators.

Little information, however, is available on which measures are likely to be most effective and whether existing interventions could contain the spread of an outbreak on campus [25].

Pedestrian traffic models were proposed to evaluate the effects of physical distancing-related strategies [22,26], and are thus applicable to the general context of exposure models in buildings or outdoor areas that include users’ behaviours and movement [24, 27,28]. Previous studies investigated factors affecting general physical distancing behaviours in different contexts to derive the effects of cultural, socio-economic and gender-related aspects on them [29–31].

Unfortunately, at the time of this research, to the authors’ knowledge, experimental data on physical distancing between pedestrians has mainly been limited to outdoor scenarios [23]. Consequently, exposure models in buildings seem to be generally based on theoretical assumptions of physical distances rather than on experimental data in indoor scenarios. Concerning educational spaces, studies exist on recommending safety measures including physical distancing, and on the consequences of physical distancing on the mental health of students [3,6,10]. However, there is still a lack of research on how students react to distancing inside the school spaces, and, mainly, in universities.

Research from social psychology has found that group members in emergencies will coordinate to stay together, even potentially putting the self at risk to help others in the group (e.g. Ref. [32], but this has only minimally been applied to non-emergency situations. Where research has focused on group coordination in corridors (e.g. Ref. [33], or looked at social groups in classroom egress [34], this has not been at a time when physical distancing was mandatory.

This paper provides a first attempt to assess students’ movement inside the university building in relation to physical distancing requirements. Strategies to ensure physical distancing in classrooms during lectures can be easily implemented because it is possible to reduce the number of people, move the activities in wider space, or ensure the management of students by teaching staff, as in many workplaces [6,35]. However, spaces connecting classrooms can be less managed and patrolled, and their use could affect students’ behaviour in terms of lack of physical distancing even if this is for a limited time [24], as they stay together when moving [18,23]. In this sense, our study focuses on the analysis of students’ movements in entering and leaving the classroom, rather than in attending lessons. This data is also compared to questionnaire-based data on individual perception of vulnerability factors while moving and using the university spaces. Analyses were carried out on a single university case study. The results provide a preliminary assessment of how pedestrians use building spaces under COVID-19 conditions. Additionally, we compare our data with on pre-pandemic data on general motion (e.g., flow, speed) to evaluate whether these are impacted by physical distancing measures. Finally, we also discuss the application of physical distancing rules for behavioural simulation modelling in buildings.

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1 https://www.cdc.gov/coronavirus/2019-ncov/community/colleges-universities/considerations.html (last access: 12/4/2021)
2. Materials and methods

This research presents the results of a study conducted in The Hague campus of the Leiden University between October and November 2020 (semester 1, block 2) when optional activities were allowed in class within the governmental and university regulations.

The experimental activities consisted of two main phases. In the first phase (section 2.1), we recorded unidirectional movement of students in university spaces while entering and leaving a classroom for lessons.

Unidirectional movement refers to corridors, stairs and bottleneck areas in the building spaces, including doors, where one-way traffic is noticed. All the participants were informed about rules for physical distancing and voluntarily participated in the experiments, but they were able to “freely” move in the environment since no physical or management safety measures were implemented (e.g.: instructions or surveillance by safety staff, staggered entrance/exit flows, signage or barriers to guide students along the environment). No student with mobility impairments were involved, and all the students were familiar with the building for learning activities. All the students followed the University rules and regulations in terms of wearing facial masks while moving inside the building and adopting personal protective measures such as physical distancing and hand hygiene.

In the second phase (section 2.2), we administered an anonymous questionnaire to students to gain an indication of their perceived vulnerability while using the building spaces at the time the movement was filmed.

2.1. Tracking methodologies and test of students’ movement

The recording took place during one of the lectures on the 13th floor of the Stichthage building, one of the University buildings that is located above the Central Station. The building is used for workgroups and optional in-class activities and has sufficient capacity for physical distancing. The focus was on the entrance door of the classroom (Fig. 1-A) and the corridor immediately beside the doorway to get to the room (Fig. 1-B). Students were filmed while entering the classroom before the lesson and when leaving the room at the end of the lesson.

The entrance and egress of students were recorded using multiple cameras placed to monitor the door and the corridor, depicted in the respective views of Fig. 1. Videotapes had a frame rate of 16fps. Two measurement areas (yellow areas) were defined, respectively placed: 1) inside the classroom and near to the door (Fig. 1-A) to monitor the possible bottleneck effects around the door while people left the classroom; and 2) along the corridor (Fig. 1-B) to evaluate unidirectional movement. The corridor beside the door was not investigated since preliminary analysis showed no bottlenecks (students moved into a single lane near the door at about 1 m physical distance). Both measurement areas had a width equal to the cross-section of the element of interest (2.0 m for the overall door, 2.2 m for the corridor) and a depth of 2.0 m, to consider the maximum recommended physical distances from national and international health organizations and regulatory frameworks. In addition, the measurement area along the corridor spanned about 2.3 m from the classroom door to avoid capturing students waiting while the door was in use.

The position of students inside the measurement areas were manually tracked using the so-called “method A” for pedestrian tracking due to its ease of application and robustness in both low-density and congested conditions. Individuals who moved alone and who were hidden from view by other people were excluded from the analysis. The open source software Tracker for image analysis was used to scale the scene according to in-situ measures and then to perform the “method A” data collection. The tracking of students’ movement at the door considered that the unidirectional movement was effectively performed into a single lane, due to the door opening and students crossing one person at a time. The perspective filter was used for the corridor measurement area to obtain a planar view of the motion ground, where of the individuals were both collected. According to the aforementioned works, we applied the “method A” by assuming the hip center as the center of mass of each individual, representing these x and y coordinates. This center of mass is associated to each moving individual per analyzed frame, allowing us to detect the percentage of time that at least two students were placed closer than the following distances:

1. t_{ut,1.0} for 2 m, as the recommended minimal physical distance when no masks are worn and there is more than 15 min of time exposure in a closed environment;
2. t_{ut,1.5} for 1.5 m, as the recommended distance between individuals in the Netherlands;
3. t_{ut,2.0} for 1 m, as the minimum recommended distance by the World Health Organization.

Evaluating t_{ut,2.0}, t_{ut,1.5} and t_{ut,1.0} allow us to detect the percentage of time p_{ut,2.0}, p_{ut,1.5} and p_{ut,1.0} (%) in which such conditions were reached, based on an approach of measuring time exposure. In this sense, p_{ut} values express the probability that people can stay closer than the recommended physical distance while moving. p_{ut} is therefore calculated as the percentage ratio between the

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2 https://www.staff.universiteitleiden.nl/binary/content/assets/algemeen/reglementen/campusprotocol-v5.0-eng.pdf (last access: 12/04/2021)
3 https://www.ecdc.europa.eu/en/covid-19/surveillance/surveillance-definitions (last access: 5/03/2021)
4 https://www.gov.nl/topics/coronavirus-covid-19/tackling-new-coronavirus-in-the-netherlands#:~:text=The%20basic%20rules%20%20such%20as,metres%20apart%20apply%20%20to%20everyone.&text=For%20smaller%20spaces%20and%20narrow%20corridors. (last access: 05/03/2021)
5 https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public (last access: 05/03/2021)
time spent by those people closer than the recommended physical distance and the overall monitored time. Statistical analysis of distance between individuals was also performed based on the distance ranges from 0 m to 2.0 m. Furthermore, the motion speeds were retrieved and compared to data on pedestrian motion in universities and public buildings before the pandemic [42, 43]. This is to determine whether macroscopic factors (e.g., speed, flow) differ during COVID-19 where physical distancing is required.

Qualitative analyses of students’ behaviours involved: 1) the number of individuals who stopped their movement to wait for other members of the same group, both while using the door and while moving along the corridor; 2) additional actions during the use of the door, such as touching the handle of any other component of the door, which could represent additional risk of virus transmission [44].

Quantitative and qualitative data were assessed by separating results for the door and the corridor measurement areas. Insights on entrance and egress conditions were distinguished by considering each related experimental sample (entrance, egress, all the data).

2.2. Questionnaire

Students were asked to fill in a short complementary online questionnaire to provide details about their perceived vulnerability to COVID-19, the danger they perceived in the environment, and to collect further qualitative information about their experiences. The questionnaire consisted of two main parts. In the first part, we asked the students a) if they were concerned about their own health due to the novel coronavirus (1 = not concerned at all; 5 = very concerned), b) how much confidence they had in the measures taken by the University to limit the spread of the novel coronavirus (1 = not confident at all; 5 = very confident) and c) how difficult it was to physical distance (1 = not difficult at all; 5 = very difficult) when walking in the corridor, entering the room, and taking a seat, as well as specifying in which situation they felt most vulnerable. In the last section, we collected demographic information such as gender and nationality and asked whether they have previously accessed the building during the pandemic.

3. Results

3.1. Students’ movement

Table 1 shows the time and the percentage of time (ptut) students spent when closer than recommended physical distancing (according to the adopted rules of 2, 1.5 and 1 m). These data refer to their movement through the door and along the corridor, in entrance (in), egress (out) and both (all, that is in + out) conditions. We report the number of detected students for each situation. An example of how to read the experimental results from Table 1 is as follows. When considering entrance (in) conditions through the doorway area, an overall time of 64s was monitored, involving the movement of 26 students. All these students remained at a distance lower than 2 m (thus closer the recommended physical distance) for 21% of the monitored time, about 13 s.

Filtering the distance data relating to students who were physically closer than 2 m, distances between the moving students are shown in Fig. 2 according to the empirical cumulative distribution function. According to Table 1, regardless of entrance and egress conditions, the time the students spend when being closer than the recommended physical distancing was lower while crossing the doorway than in the corridor. This effect could be due to the single lane formation. According to Fig. 2-A, the probability of students being closer than the 1.0 m recommended physical distance is lower than the 0.4 m, while physical contact between the individuals is rare (distances of about 0.3 m–0.4 m). Differences among students egressing and entering is limited. Possible reasons for students being closer than 2.0 m may be due to students usually standing beside the door while moving if there are other moving individuals behind them (an example is shown in Fig. 5). According to this behaviour, the distance probability values are close to 1 for distance values in the range from about 1.4 m to 1.6 m (see Fig. 2-A). These distance values are equal to about two people with their arms stretched out.\footnote{https://multisite.eos.ncsu.edu/www-ergocenter-ncsu-edu/wp-content/uploads/sites/18/2016/06/Anthropometric-Detailed-Data-Tables.pdf (last access: 08/03/2021)} Waiting behaviours seem to be limited for the students entering
the room (8%), thus affecting the minimum values of distance in these conditions as shown by Fig. 2 - A (0.6 m for the entrance sample rather than 0.3 m for egress sample). In contrast, waiting behaviours were more consistent in the egress conditions (35%), because students (i.e., the first students leaving the room) seemed to prefer gathering as a group before opening the door and exiting the room. This is in line with previous research indicating how group members seek being together (e.g., staying behind to find others before leaving in emergency conditions, and leader-follower phenomena, see Refs. [20,32,45]. An example of such behaviour is shown in Fig. 3 - A.

While moving in the corridor, individuals did not need to move into a single lane. Therefore, the percentage of time $pt_{ut}$ spent by students closer than the recommended physical distance is higher when crossing the doorway, as shown by Table 1. However, Fig. 2 - B shows that the empirical cumulative distribution function for the corridor area has a lower slope for those at the door area, thanks to the width of the corridor allowing people to move towards higher values of physical distance, i.e., keep further apart. The distancing phenomena were more relevant when entering the room rather than when exiting the room. For instance, assuming the probability

| measurement area and condition | in | out | all | in | out | all |
|-------------------------------|----|-----|-----|----|-----|-----|
| overall monitored time [s]    | 64 | 84  | 148 | 51 | 116 | 167 |
| overall number of monitored students [person/m$^2$] | 26 | 35  | 61  | 23 | 46  | 69  |
| 2.0 m apart - $pt_{ut,2.0}$ | 21% | 25% | 23% | 49% | 54% | 53% |
| 1.5 m apart - $pt_{ut,1.5}$ | 21% | 24% | 23% | 39% | 48% | 46% |
| 1.0 m apart - $pt_{ut,1.0}$ | 12% | 14% | 13% | 20% | 19% | 19% |

Fig. 2. Empirical cumulative distribution function for door (A) and corridor (B) flows by distinguishing entrance (in – dashed lines), egress (out – dotted lines) and whole (all – continuous lines) samples.

Fig. 3. Relationship between the group size and physical distance ($pt_{ut}$, 2.0) depending on the area (corridor or doorway) and conditions (in/out in the corridor, in/ out through the door).
level is equal to 0.5 in both conditions, the distance with other students while entering the room was 1.6 m, and while exiting the room was 1.2 m. This result could be influenced by the effect of the door as a bottleneck along the path [46]; J [40]. In this condition, people also avoided stopping and waiting for other students. Distances smaller than the 2.0 m recommended distance were however limited during the time, but students seemed to generally remain closer when they are in smaller groups (see Fig. 3). Fig. 3 provides a further visualization of the relationship between the group size and physical distance ($p_{tr,2.0}$) depending on the area (corridor or doorway) and conditions (in/out in the corridor, in/out through the door). It suggests that there are smaller differences in physical distances $p_{tr,2.0}$ for groups composed by 3 or more persons.

In comparison, while exiting the door, 26% of students who first reached the corridor (Fig. 4-B1 on the right) stopped to wait for the other individuals who were still leaving the room (Fig. 4-B1 on the left, the student with the red shirt), and then they began moving together when the group had gathered (Fig. 4-B2).

The experimental speed values range from about 0.2 to 1.5 m/s (median value: 0.8 m/s; for doorway, minimum values of 0.0 m/s are due to students waiting to enter or leave the room), and so they are lower than values found in previous studies on individual motion in “normal” (non-evacuation) conditions (about 1.5 m/s) [47], as well as those concerning educational buildings (ranging from 0.7 to 1.5 m, median value: 1.25 m/s) [42]. However, the values seem to be more in line with the values for general public places (0.5–0.7 m/s) [14,43] and research suggesting that group members reduce their speed when maintaining close proximity [18]. Slight differences can be seen for corridors and doors, as well as for entrance and egress conditions. Similarly, density-specific flows pairs form the experiments are close to the general trends of literature works [38,48], with a difference of –25% in maximum flow value at bets density conditions (about 2 persons/m²). In this sense, the COVID-19 conditions do not seem to affect the response of the individuals, but it is noteworthy that differences between experimental outcomes and previous research may be impacted by the characteristics of the individuals, such as age, gender, grouping, clothing and physical ability [42].

Finally, 85% of students touched a limited area of the door surface, as qualitatively traced by Fig. 5, rather than using the door handle.

The phenomenon could be partially influenced by the fact that the door had no door lock system, thus allowing people just to push...
the door to enter the room. However, is it noteworthy that the same behaviours were noticed both by the first individual in the group opening the room and the following individuals. At the same time, the door pushing and holding phenomena were limitedly performed to wait for other individuals while moving, especially while entering the room (8% of students), thus highlighting how the regular distance between the individuals seems to be the leading factor influencing movement through doorways.

3.2. Questionnaire

A total of 38 students took part in the questionnaire, of whom 51% were females, 86% were Dutch, and 91% had experience accessing the building. Overall, the questionnaires results suggest students were unconcerned to moderately concerned about their own health ($M = 2.82, SD = 1.12$). They also were neutral to fairly confident ($M = 3.68, SD = 0.98$) in the measures taken by the University with 70% of the students stated they were fairly to very confident (score from 3 to 5 in the related Likert scale).

Additionally, outcomes from experimental analyses of Section 3.1 are also supported. Students rated quite low difficulty to physically distance from others in the corridor ($M = 2.25, SD = 1.30$). They reported mainly having difficulty keeping physical distancing when entering the room ($M = 2.40, SD = 1.25$), i.e., while crossing the doorway. This corresponds to the values in the cumulative distribution function in Fig. 2-A, that are shifted towards lower values of physical distancing (e.g., close to 1 m). As discussed in Section 3.1, the close proximity of students was mitigated by the single lane formation while crossing the door, thus limiting $p_{st}$ as shown by Table 1.

Finally, students seemed to be aware of COVID-19 exposure while moving along the corridor, since 44% of the students felt more vulnerable in this space due to limited ability to keep the required physical distance. Participants reported higher vulnerability to COVID-19 (i.e., scores 4 or 5 in the Likert scale) when trying to keep physical distance in the corridor (44%) compared to in the doorway (38%). Comparing these results to the behavioural data in Section 3.1, students seem to have a misperception of their vulnerability in corridors versus doorways since students perceived less high risk at the doorways despite being in closer physical proximity in this space. On the contrary, they feel more vulnerable while moving along the corridor, maybe because they are freer to move than at the doorway (the corridor is wider than the doorway, thus allowing multiple lanes). Anyway, the corridor seems to be wide enough to allow students to keep further distance from surrounding individuals (see Fig. 2-B).

4. Discussions

The research findings can be summarised in three keyways: 1) behavioural findings of students’ movement data inside a university building is matched with their self-reported perceived vulnerability of COVID-19 spread; 2) implications for virus spread in university buildings and safety management; and 3) implications for behavioural modelling and simulation of pandemic conditions in buildings.

Regarding the behavioural findings, the results show that students generally adhered to the physical distancing guidelines when moving inside the university building. However, the presence of environmental constraints such as doors and corridors affected their distancing behaviour. For example, using doors was associated with a bottleneck phenomenon that resulted in single lane formation while crossing the doorway, and this was subsequently associated with reduced distance between students. Interestingly, the questionnaire data suggests that students may have misperceived their level of vulnerability since they reported higher risk in corridors (where they were more physically distant) compared to doorways (where they were less physically distant). Behavioural results from Section 3.1 underline that there was lower difficulty for students to keep appropriate physical distance in the corridor due to the wider space, but the students’ self-reported perceived vulnerability to COVID-19 was slightly higher in the corridor.

Overall, the density levels are lower when students moved along the corridors. The space available in the corridor suggests that students could effectively improve their spatial distribution to appropriately physically distance. However, the tendency for students to move in groups influenced the use of space and physical distancing and shows that group clustering occurs even in the COVID-19 pandemic [23]. Notably, the higher the number of students in the group, the higher the probability that they would move closer than recommended physical distance. In line with a microscopic representation of pedestrian movement [47], the results suggest that students in larger groups seem to better avoid neighboring individuals while moving, thus reducing the time spent closer than 2 m with others. The results indicate several insights into the implications for virus spread and safety management. They provide a probability-based approach to estimate the time during which the students can remain in exposed conditions to COVID-19 due to physical proximity. From a time-based standpoint, distances of $p_{st,ut,1.0}, p_{st,ut,1.5}$ and $p_{st,ut,2.0}$ from Table 1 can be directly used to assess the possible exposure time in university buildings. If we apply the time spent at a distance of $p_{st,ut,2.0}$ outlined in Table 1 to an exposure time of 15 min (considered by research to be the critical time needed for COVID-19 spread [3]), we could derive that people can spend about 189s while being in closer physical proximity than recommended. Thus, this ratio in $p_{st,ut,2.0}$ implies that 15 min of closed proximity can be reached in 75 min of movement in university spaces.

The reduced physical distancing in the corridors suggests that safety management should focus on the times and locations when students are most likely to breach physical distancing guidelines (i.e., when students change between lessons) and ensure sufficient physical capacity to maintain physical distancing. For example, phased timetabling could be introduced to minimise occupancy of the corridors at any one time, or management strategies for encouraging single lane formations in corridors could be implemented to decrease the probability of students being in close physical proximity [22]. However, we acknowledge that single lane formations in corridors could highly impact the use of the building and the pedestrian flow. We also note the importance of cleaning surfaces and hands to reduce COVID-19 spread [44], including working surfaces door handles, and all their parts that can be touched by people during their use (i.e. areas of doors near the handles).

Finally, the main implications on behavioural modelling and simulation concern the definition of rules to predict that people can remain closer than the recommend physical distance while gathering and walking in building spaces. Besides the quick-to-apply time-
Based on rules given by Table 1 and discussed above, Fig. 2 can offer the bases for a model to describe the individual probability of a person remaining closer than the distances recommended by different regulations (in this study, while students used face masks inside university common spaces). Proximity rules are currently used by some simulators to evaluate the possibility that close contact between individuals can lead to virus spread (e.g., Refs. [22, 24, 28]). These simulators can take advantages of our data to further base their models in behavioural evidence.

Moreover, the evaluation of timing of the users’ movement can be performed basing on the density-flow correlations, while the probability of virus spread for people in close proximity can be assessed thanking to the distance probability rules in Fig. 2. This is particularly suited to a macroscopic and stochastic approach to assessing virus spread (both for COVID-19 and future pandemics) where the probabilities are applied to all people in the simulation. The rules can be also applied to model the paths and trajectories of each of the users in the building, according to a microscopic approach to pedestrian simulation.

There are some limitations to the current research that should be noted. Most research investigating group movement and clustering has used top-down assumptions of group cohesion based on observed proximity and group formations, rather than using a bottom-up approach to examine the peoples’ motivations for behaviour [49]. To fully understand the reasons for group clustering in the current research, the questionnaires could have included items measuring the extent to which students saw others as group members (for example items see Ref. [50]). This would have allowed a unique combination of understanding both the physical and psychological factors contributing to the observed group behaviour. Another limitation is that there was individual variability in each experimental condition that limits direct comparison, e.g., some students chose to individually enter or leave the room, and it was not possible to monitor some students since they were obscured from the camera by other people. Finally, the sample size was affected by external factors since the Dutch government stopped lectures which limited the number of the performed tests as well as the number of participants.

5. Conclusion

As educational institutions and universities decide to provide in class activity or to adopt a blended education, students’ adherence to physical distancing and group behaviour is a priority topic that requires close analysis. Proper physical distancing according to national and international health organizations can reduce individual exposure to infectious agents and facilitate the use of buildings. This paper uses an experimental-based approach to evaluate if and how students adopt physical distancing while moving along corridors and while crossing through doorways.

This is the first experimental quantification to the authors’ current knowledge. Such an approach can be implemented into simulation models to verify/estimate the potential of behaviour-related transmission during people’s gathering in an indoor environment. In addition, the results can provide interesting insights for the educational decision-makers regarding key risk areas in buildings (e.g., frequently touched surface areas, areas exposed to more critical proximity between students, students’ perceived vulnerability in different building areas).

Since the current work focuses on unidirectional movement in simplified straight corridor scenarios, further studies on other conditions (e.g., bidirectional flow, crossings) and other spatial constraints (e.g., multiple doors, different geometric shapes of the corridors) should be investigated to determine possible differences in how the students use the building. This data could additionally provide evidence on the effectiveness of one-way traffic paths in buildings in encouraging pedestrians to physically distance, as well as ideal layout shapes to support physical distancing strategies.

Further studies are also needed to enlarge the database, such as by investigating how types of buildings (e.g., including their layout) and how their use impacts exposure to COVID-19 (i.e., those open to the public such as museums, transportation hubs and workplaces). Other cultural and geographical contexts should be explored to improve the reliability of the results, and to move towards understanding the conditions that can alter peoples’ physical distancing. Finally, the same behaviour-centred approach could be also applied to other kind of respiratory viruses to plan for future pandemics.

Ethical considerations

No personal identifiers of students or University staff have been shared with third parts and all results are presented in anonymized aggregate information and not at the individual level. All the information collected through the videos and the questionnaire are completely anonymous.

According to the Leiden University regulations in relation to the COVID-19, starting from 15 October it is compulsory for everyone in buildings to wear a face mask. Thus, students standing or walking, are required to wear a face mask. Recordings were taken only of people in movement (walking in the corridor, entering the room, sitting, exiting the room), with all the students wearing a face mask; this allowed investigators to avoid recording face and personal features that could be used to identify the participants.

The research received the confirmation of favourable opinion from the Faculteit Governance and Global Affairs Ethics Committee (Ethics application reference number: 2020-020-IAGA-Bartolucci).

Students were informed about the scope of the research; the questionnaire used for the data collection explicitly stated the scientific purpose of the study survey and the use of data; each responder provided verbal informed consent prior to participation and voluntarily decided whether to participate or not. Furthermore, students could withdraw from the research at any time.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to
influence the work reported in this paper.

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