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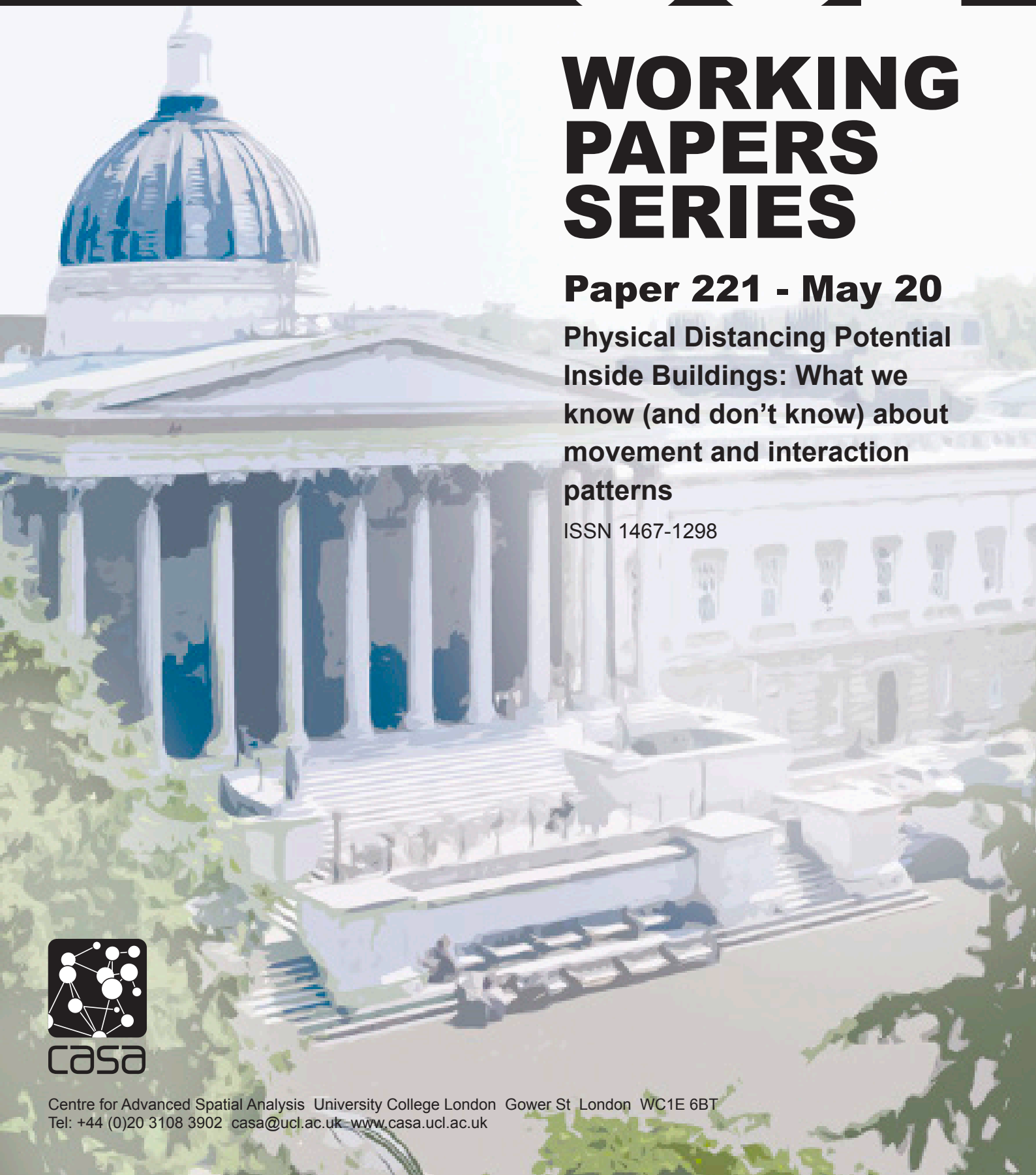

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PHYSICAL DISTANCING POTENTIAL INSIDE BUILDINGS

What we know (and don't know) about movement and interaction patterns

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Background

The global Covid-19 pandemic has forced us to reconsider the design of the built environment. This review was produced at speed in April 2020 as a working paper to reflect on the state-of-the-art knowledge on movement and interaction inside buildings.

Covid-19 and the built environment

An excellent up-to-date review article summarised the role the built environment plays for efforts reducing transmission pathways for Covid-19 (Dietz et al., 2020). It highlights the fact that human to human transmission is the most likely risk inside buildings, although surface contacts and airborne transmission beyond six feet distance (Li et al., 2020) could also play a role. The article suggests mitigation strategies relating to hygiene precautions but also humidity, ventilation and daylight. It touches upon building layouts very lightly, building on insights established earlier that showed how indoor bacterial communities were distributed following architectural design principles (Kembel et al., 2014).

The importance of building layouts

Buildings provide mechanisms to bring people together or to keep them apart by structuring movement flows according to a building's spatial layout. A building entrance and lobby are used by all building inhabitants and visitors to come in and go out. Central staircases, elevators and the main circulation corridors distribute people. Research in the tradition of

space syntax shows how the configuration of a building, i.e. how spatial elements are connected to form a network of spaces plays a major role in those distribution patterns.

Space syntax as a method and theory

Space syntax considers the connectedness of spatial elements inside a building (rooms, corridors, staircases, lobbies, open spaces, etc.) and analyses how the configuration of the network as a whole predicts the intensity of space usage patterns, such as movement flows and subsequently also patterns of face-to-face encounter. Connectedness is considered locally or globally: 1) local connectedness can be the numbers of rooms leading off a corridor, or the size and characteristics of a viewshed from a particular vantage point (called isovist); 2) global connectedness is the average path length through the network from a particular location, either in terms of visibility (how often do you need to 'look around the corner' from a location on average to visibly access all other spaces in the building), or in terms of lines of potential movement (called axial lines or segments).

Spaces with a relatively short average path length are called integrated, while spaces with a long path length are called segregated. Space syntax research has shown that integrated spaces tend to attract more movement and encounters, while segregated spaces are more naturally quiet. Therefore, space syntax allows modelling, simulating and predicting likely usage patterns by virtue of analysing the building geometry and plan layout.

Traditionally, space syntax research considers interactions as a positive by-product of movement, leading to chance encounters, collaboration and innovation (Hillier & Penn, 1991; Penn, Desyllas, & Vaughan, 1999).

In the context of Covid-19 and understanding the physical distancing potential embedded into the structures of buildings, we need to think of opportunities for avoidance of contact.

Building types

Space syntax has different implications and predictive powers depending on the different building typologies. Typically, syntactic modelling best captures generative, exploratory types of movement and behaviours (so called 'weakly programmed') and only to a lesser extent targeted, purposeful behaviour ('strongly programmed'). Therefore, existing insights as well as new emerging research will be captured type by type in the following.

Hospitals

- Rich space syntax related literature on hospitals and long-standing research tradition in space syntax
- When nurses and physicians interacted while sitting, they preferred spaces that help maintain high levels of awareness. When nurses walked and communicated while walking, they avoided spaces with good global accessibility and visibility. Both doctors and nurses walked more in spaces with higher control over neighbouring spaces (Rashid et al., 2014)
- Formal communications usually leave little room for uncertainty while in corridor conversations there is a tolerance for contingencies (Iedema et al., 2005). Corridors

also provide space where usual professional hierarchies can be suspended. In this neutral zone, nurses, doctors, physical therapists, and other health care professionals interact spontaneously and opportunistically (Becker, 2007).

- Well-constructed ward neighbourhoods are those in which openness, local connectivity and global visibility, are present, facilitating both formal and informal interactions (O'Hara et al., 2018)
- Nurse assignments with greater average integration (shorter path length) were associated with higher number of entries to patient rooms and the nurse station allowing nurses to participate in two critical nursing activities – patient care and staff interaction. Number of entries to patient rooms correlated negatively with average time per visit and positively with total time spent in patient rooms meaning that nurses either had fewer but longer visits or more frequent but shorter visits (Hendrich et al., 2009)
- Doctors were most often found in areas of generic high visibility, where nurses tended to position themselves so that they maximise their visibility of patient beds (Lu & Zimring, 2009, 2012)
- Overall information exchange between doctors and nurses decreased in decentralised nurse station unit and a significant reduction in social communication occurred among nurses. Walking distances significantly decreased too, and nurses spent less time in patient rooms. Hua et al. (2012). Real et al. (2017) found that decentralised nursing stations reduced nurse-to-nurse interactions and teamwork while increasing interdependencies and teamwork with other healthcare professionals.
- Sub-areas with larger viewsheds and shorter path length resulted in fewer trips to patient rooms because of better visibility (Choudhary et al., 2010)
- Nurses in a larger unit interacted less, made fewer extra stops and walked significantly shorter extra distances when getting medications than in a smaller unit. It was suggested that this could be as a result of lower visibility levels and thus fewer opportunities to see someone in the larger unit. It was suggested that nurses' perception of distance also played a role and the shorter the perceived distance the more frequent trips and extra stops the nurse would make. (Seo, Choi & Zimring, 2011)
- Comparing 31 NHS hospital wards and analysing the potential of local visibility for care givers emanating from key movement paths (patient bed to patient bed, patient bed to nursing station, patient bed to medication room and nursing station to medication room), a 'Spaces for Communication Index' SCi was calculated, since local visibility correlated with communication opportunities. SCi predicted reasonably well which wards provided better healthcare quality (using data from the Care Quality Commission) with $p = 0.005$ and can be used as a tool to assess layouts and anticipate certain levels of care quality. The higher the index, the better the quality of care. (Pachilova & Sailer, 2019, 2020)
- The following insights come from the newly published PhD dissertation of Dr Rosica Pachilova, UCL (Pachilova, 2019):
    - Based on an in-depth analysis of 6 inpatient wards in 3 different hospitals (using space syntax analysis, structured observations of 102 healthcare workers, semi-structured interviews with 36 staff, questionnaires and data on communication patterns using wearable devices)

- The size of the ward did not affect walking distances and other factors such as the specialty of the ward had a greater effect on the length of walking. Healthcare providers in ICUs had shorter walking paths on average compared to nursing wards because of the nurse to patient ratio.
- The size of the ward affected activities and conversations and smaller wards resulted in a more dynamic environment with shorter duration of activities and more frequent conversations while healthcare providers in larger units had longer duration of activities and fewer conversations.
- On average nurses had 0.74 face-to-face conversations per minute, while doctors communicated 0.59 times per minute. This shows how frequent communication events are inside hospital wards.
- The nursing station was used more by doctors than nurses.
- In general, roles that required the collection of patient information e.g. doctors and consultants, had greater proportion of conversations that involved more than one communication partner while roles that transmitted information e.g. nurses, had more one-to-one conversations.
- The ward layout made the most difference for nurses in terms of walking distances, frequency and duration of activities while it did not affect consultants or physiotherapist who had more programmed activities.
- Distance between healthcare providers affected the frequency of their conversations. However, distance did not make a big difference for small and compact ward layouts and made more of a difference for more complicated layouts with lower intelligibility.
- The higher the integration a healthcare worker accumulated along their work path, the more frequent and the more time overall they would spend in conversations.

Offices

- Rich space syntax related literature on offices and long-standing research tradition in space syntax
- Movement in offices clusters in circulation spaces (Hillier & Penn, 1991) and away from walls (Penn, Desyllas, & Vaughan, 1999)
- More centrally located (integrated) spaces and building parts attract more movement than more segregated locations (Hillier & Grajewski, 1990; Major, Indraganti, Ahmad, & Tannous, 2019; Penn et al., 1999; Rashid, Kampschroer, Wineman, & Zimring, 2006)
- The location of the entrance is important (Penn et al., 1999), but also other facilities such as photocopiers and watercoolers (Fayard & Weeks, 2007), tea points and toilets (Sailer, 2007) in order to distribute and attract movement
- Multiple work points tend to also generate movement such as researchers having both labs and offices to travel between (Kabo, Hwang, Levenstein, & Owen-Smith, 2015; Owen-Smith, Kabo, Levenstein, Price, & Davis, 2012)
- Movement also tends to be towards other colleagues (Wineman, Hwang, Kabo, Owen-Smith, & Davis, 2014)

- More accessible and visible colleagues will receive more unscheduled visits while less accessible colleagues will substitute these interactions with email and telephone (Toker & Gray, 2008)
- Emergent (and yet unpublished) insights from the almost completed PhD dissertation of Petros Koutsolampros:
    - Based on a big data sample consisting of 41 companies, in 213 floors with a total office area of 249,926 m^2 and belonging to a variety of industries from legal and media to manufacturing and retail. The number of desks in the sample was 37,764 with a total of 760,437 observations of people.
    - Attractors (facilities, entrance) are the most important generators of movement within a floor
    - Floors with higher densities of desks per floor area tend to have more movement
    - In dense workspaces more movement is observed between colleagues
    - It is more likely to observe movement in open-plan workspace circulation than in corridors
    - Wider circulation between desks in open workspace means less density of movement for a floor/space because the amount of people moving remains the same over a larger space
    - Entrances and building-wide canteens are important as generators of movement from other floors
    - Centrally located spaces are more likely to attract movement, but workspaces are generally more centrally located because the "edge" floors (top/bottom) tend to be other facilities (storage, canteens, lobby, meeting rooms etc.)
    - In general, the above effects captured 25-35% of the variation in the data, with service floors (those that contain canteens and entrances) being the most predictable at 34-35% while floors that contained workspace were more varied.

Schools

- Emerging topic for space syntax related research, yet only a few relevant studies on movement and encounter patterns
- Comparing 4 middle schools in the US, a study (Pasalar, 2003) found that compact layouts (with academic houses and multiple floors) led to a clustering of classrooms and students reported have more contact with students in the same grade. In contrast, spread out finger layouts (on a single floor) showed higher rates of contact across grades and students reported having more friends across the school.
- Using wearable sensors, a study of a primary school in France established patterns of face-to-face contact (Stehle et al., 2011); findings included that each pupil was in close proximity at some point during the school day with 50 other people on average; the average duration of contacts was 33 seconds and 88% of contacts lasted less than 1 minute; only 0.2% of contacts lasted more than 5 minutes. This shows how fleeting encounters in primary schools are. Contacts were driven by schedules and temporal structuring and were most intense within a class, then decreasingly within a grade, among teachers and across grades.

- Emergent (and yet unpublished) insights from the almost completed PhD dissertation of Ahmed Tarek Zaky Fouad:
    - Movement and encounters in school buildings are primarily determined by the school schedule which dictates where the students will be at what time.
    - According to this schedule, movement pattern evolve; either in the form of circulation: from a starting point, through space and towards a destination; or in the form of various activities: queuing for the kitchen during lunch time, movement of players in the football pitch, movement of students organizing the books in the library space.
    - Circulation breaks between classes have the highest rates of movement and encounters especially within the corridors. Seven types of movement are observable: 1) Student moving in one direction (from or to a lesson); 2) Students moving in the opposite direction (from or to a lesson); 3) Students queuing to get into a classroom; 4) Teachers moving in one direction (from or to a lesson); 5) Teachers moving in the opposite direction(from or to a lesson); 6) Teachers moving around to supervise the corridors 7) Student or teachers doing other activities (filling a water bottle from the dispenser in the corridor, teacher-student quick talk over their behaviour in class, etc).
    - Lunch break comes second after circulation breaks in terms of rates of movement. Movement is less intense as the spaces are less confined, and there are more options where to go and what to do. However, certain activities are desired by a large number of students at a specific point in time: queuing to get food at the kitchen, the gathering for several students around a laptop in the library, collective sports activities (football, basketball).

Supermarkets

- Far reaching research into consumer behaviour, buying decisions, types of shoppers (quick trip, fill-in and stock-up) as well as into in-store movement patterns is provided by the book ‘Inside the mind of the shopper’ (Sorensen, 2009)
- Sparse research on layouts in relation to behaviour of shoppers;
- Following observations of the detailed movement paths of 480 shoppers in a medium size supermarket (Gil, Tobari, Lemlij, Rose, & Penn, 2009), it was concluded that movement followed product location (i.e. shoppers seeking out bread, milk, etc.) to a higher degree than following configurational patterns. Shopping behaviour was found to be rather complex, yet distinguishing five different profiles (the specialist, the native, the tourist, the explorer, the raider) helped unpack certain characteristics of behaviours (e.g. length of stay, use of trolleys, visit to segregated areas, walking speed, etc).

Rail stations

- Sparse research on layouts in relation to behaviour of travellers;
- Observations of usage and movement patterns of two London railway stations, Victoria and Euston (undertaken in 2000) highlighted that movement clustered around central travelling functions, such as entrances / exits, but also railway and

Underground connections. Static occupancy showed densely packed patterns, mainly around ticket offices and departure boards (Paksukcharern, 2003).

Recommendations on how to potentially minimise encounters and proximity in buildings

In general, for all building types, the following recommendations could be considered:

- Use more entrances if possible
- Buildings with ring-like circulation spaces could introduce certain corridors as one-way systems
- Buildings with more than one circulation core could designate one staircase for upward and one for downward movement
- Use of contactless door openings to minimise touch
- Consider floors of buildings as self-sustained entities in itself and minimise travel between floors.

Recommendations specific to building types:

- Offices: reduce seat density per floor / area
- Offices: increase corridor width where possible (e.g. in open-plan areas by taking out one workstation from a row of desks)
- Offices: encourage the use of email/telephone/messaging applications even for colleagues sitting a few desks away
- Offices: spread out facilities as much as possible to reduce cross-floor movement
- Offices: introduce tea points or watercoolers on each floor and close canteens (potentially convert to workspaces)
- Offices: bring team-related facilities (team-assigned storage) to the same floor as the team
- Offices: evenly spread desks so that they are not all centrally located or clustered in the building
- Offices: consider assignments of specific facilities at specific times i.e. spread out the time of arrival and assign entrances for each person, suggest an assignment of meeting rooms, kitchens per time/per team
- Schools: The best option to control distancing is to control the school schedule. Other important factors are type of corridor (rooms on one side, or on two), corridor width, the number of spaces it serves, its connection to the vertical circulation cores and their number. These are design factors that cannot be altered for the short term and would require a long-term building alteration plan, which again renders the schedule the key solution to control social distancing in schools.
- Schools: Consider a differentiated schedule, whereby there are no simultaneous classes in the same wing (accessed through the same corridor). Instead, class start time is pushed back by 5-7 minutes minimum to avoid simultaneous circulation of different class groups. This will lead to reducing the number of classes per day (which is desirable anyway to avoid high risk of encounter)

- Schools: the typical 30-45 minutes lunch break could be replaced by shorter slots (10 minutes) for each group of students, where no more than a certain number of students should be together.
- Schools: rather than having students moving, let teachers move. Group lessons into chunks that minimise movement.
- Schools: consider schools like supermarkets: reduce number of students per space (especially the circulation space), keep proper social distance during circulation and avoid unnecessary presence.
- Schools: in certain schools with dense and large populations, a good solution might also include the division of the school day over two sessions, where the student population is divided to attend either a morning/afternoon session (8:00-1:00 preferably the younger group) or a full afternoon session (1:15-6:15 preferably the older group)
- Schools: consider tutorial groups that are smaller than a typical class and last for shorter periods of time so that one class period is divided into smaller sessions and so is the student body. For example, a class of 60 mins with 30 students is replaced by 20 min sessions for 10 students each.
- Schools: create a hybrid schedule of distance learning from home and class-based learning. Technology/computer based schooling could take place from school premises, so that children go to school but do not follow the typical daily schedule.
- Supermarkets: consider changing product placements to minimise traversing whole shop to get essentials such as milk, bread, etc.
- Rail stations: crowd control seems key, i.e.:
    - Encouraging active modes of travel to reduce number of users and density of occupation of rail stations;
    - Move ticket sales online (print at home tickets);
    - Announce platforms for departures and arrivals online / via apps to minimise waiting underneath boards;
- Rail stations: consider disentangling movement paths and avoiding intersection of different flows where possible, e.g. by dedicating certain entrances / exits to particular routes and minimising overlapping paths in tunnels

Other considerations

Further research of relevance might include fine scale observations of movement and interaction between pedestrians on pavements and how they behave as couples and interact with others and street furniture etc. (Kerridge, Armitage, Binnie, Lei, & Sumpter, 2004) as well as the ground-breaking work of William H Whyte in observing space usage in public squares in New York (Whyte, 1980).

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