Pedestrian and Evacuation Dynamics 2023

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Contents

Version: 28/06/2023

About

Pedestrian and Evacuation Dynamics (PED) is a bi-annual international conference series established in 2001. This booklet contains the abstracts of the contributions to its 11^{th} installment hosted by the Crowdflow Research Group at Eindhoven University of Technology (The Netherlands) between June 28th and 30th 2023.

The conference welcomes contributions from the whole PED research range. This is a multi-disciplinary and inter-disciplinary field at the interface between engineering, psychology/sociology, computer science, automated vision, applied physics/mathematics and more. Crowd modelling approaches have evolved in the last decades from hand calculations to advanced simulations encompassing a wide selection of methods (e.g., agent-based modelling, force-based modelling, cellular automata, etc.). Experimental studies focusing on monitoring pedestrian movement and behavior have seen a great deal of research exploiting advancements in AI, machine learning, VR/AR, game development and 3D modelling. This allowed the development of new theories and deeper investigation of key crowd movement and behavior phenomena. The scope of the PED conference has also evolved to range from traditional topics, such as pedestrian planning and safety evacuation, to new areas, as evidenced by the COVID-19 outbreak, which put the field under the spotlight for almost two years. Crowd management solutions benefit greatly from advances in the field, making the PED conference a unique opportunity to discuss the latest and most advanced research in the community.

The focus of PED2023 is deliberately broad and embraces:

- Pedestrian and Evacuation dynamics
- Pedestrian and Evacuation modelling
- Fundamental physics aspects of pedestrian flows
- Experimental research in the PED domain
- Safety, security and circulation studies
- Applications, best practices, field deployments in outdoor spaces, built environment and transportation

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- **Web:** `https://ped23.phys.tue.nl`
- **Twitter:** `@PED2023` `https://twitter.com/PED2023`
- **E-mail:** ped23@tue.nl
- **Venue:** Eindhoven University of Technology Campus, Eindhoven, The Netherlands
  - Auditorium building
- **Host:** Crowdflow Research Group, Department of Applied Physics and Education Science, Eindhoven University of Technology. `https://crowdflow.phys.tue.nl/wordpress/`
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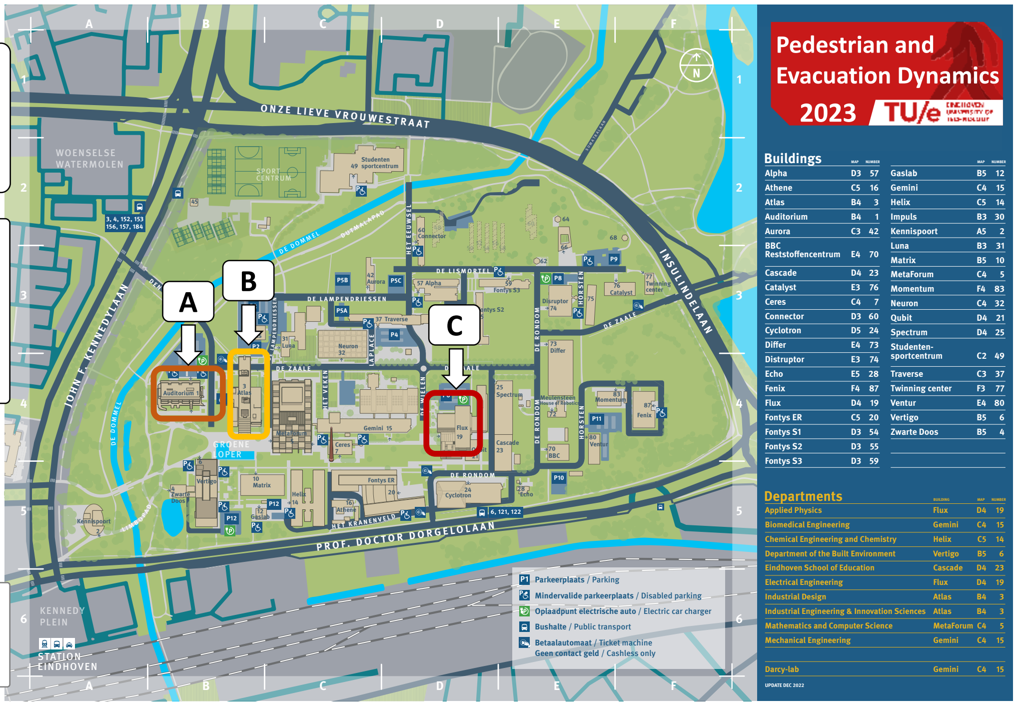
Maps

Campus map

Main Conference
June 28th-30th
Location: **A (Auditorium)**
Start time: H9.00

PhD Workshop
June 27th
Location: **A (Auditorium)**
Start time: H10.00

Lecture prof. A. Schadschneider
Location: **C (Flux)**
Room 1.02 (1st floor)



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Steering committee meeting
(committee only)
June 28th H18.30
Location: **B (Atlas)**
Room: 2.215 (2nd floor)

Auditorium map

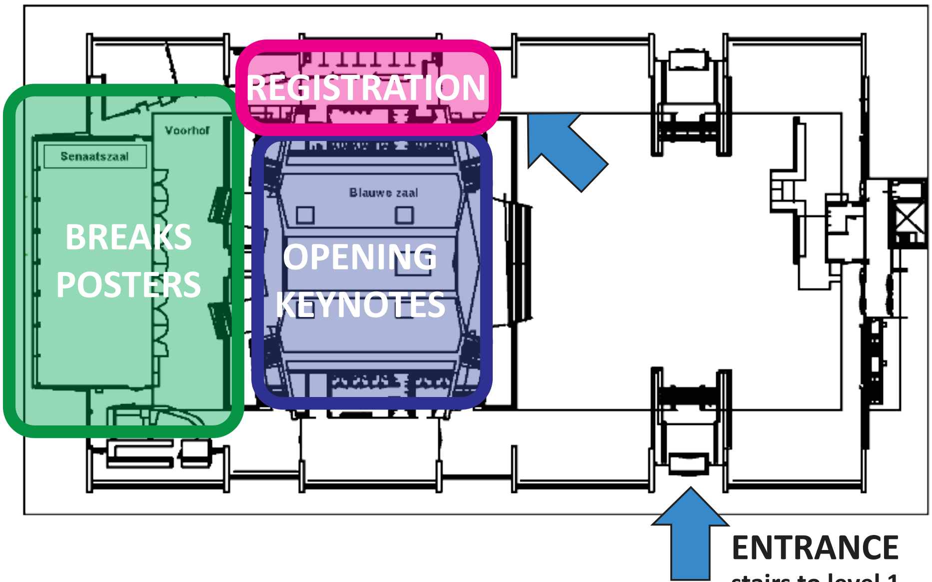
Pedestrian and Evacuation Dynamics 2023

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Auditorium Building

Main location

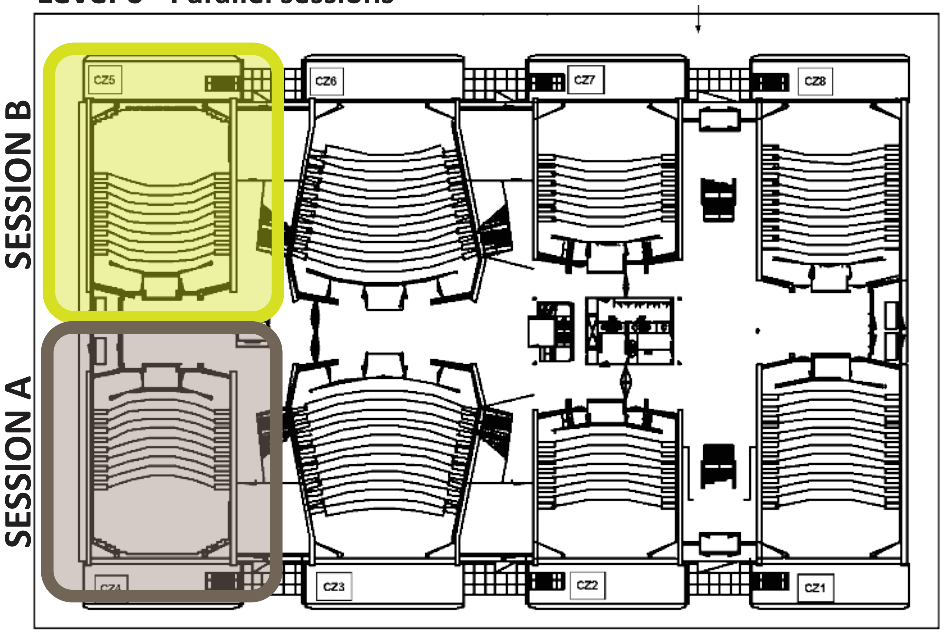
Level 1 - Main level, keynotes, breaks, posters, workshop (lev. 2)



ENTRANCE

stairs to level 1

Level 0 - Parallel sessions



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Keynote speakers

Each of the three days of PED2023 will start with an inspirational talk by our keynote speakers.

Keynote speakers: Dr. Max Kinateder, Dr. Denise McGrath, Prof. Daniel R. Parisi

Dr. Max Kinateder

Dr. Max Kinateder serves as an Associate Research Officer at the National Research Council of Canada and as an Adjunct Research Faculty in Cognitive Science at Carleton University. His research focuses on human behavior in fire, with a particular emphasis on evacuation decision-making and movement in building fires or wildfires. The overall aim of his work is to contribute to a better understanding of perception and action in complex emergency situations and to increase safety for all. To do this, he uses empirical methods ranging from controlled experiments in immersive virtual and augmented reality to field observations. He holds a PhD in psychology from the university of Würzburg, Germany.

Dr. Denise McGrath

Dr. Denise McGrath is a faculty member at the School of Public Health, Physiotherapy and Sports Science, University College Dublin. With expertise in the analysis of human movement from a biomechanical perspective, she works across disciplines and sectors on applied research that addresses a range of problems in the health, wellbeing and technology spaces. She has worked with ageing and clinical populations as well as elite athletes, employing wearable and video technologies to capture movement data. She has collaborated with academic and industry-based researchers in the field of crowd flow and fire safety to create novel insights into how movement can be modelled based on individual gait characteristics.

Prof. Daniel R. Parisi

Daniel R. Parisi is a Professor at the “Buenos Aires Institute of Technology” (ITBA) and a Researcher at the “National Scientific and Technical Research Council” (CONICET, Argentina). Daniel graduates in Physics in 1998 and received his doctorate from the University of Buenos Aires (Argentina) and from the National Institute of Applied Science at Rennes (France) in 2003. Since then, he has dedicated to basic and applied research on active matter systems in general, and in particular, to pedestrian dynamics. Area in which he has collected experimental data; developed validated models, and transferred knowledge to simulation software and consultancy. In 2006, he co-founded “Urbix”, an Argentinean tech-based company that provided pedestrian flow simulation and characterization. More recently (2019) he was awarded a “Human Frontier Science Program” (HFSP) grant as part of an international team. Currently, he is the head of the “Center of Physical, Biological, and Social Agents” (CAFiBiS) at ITBA.

Conference timetable

Wednesday, 28th of June

8:00–9:00	**Reception and registrations**	
9:00–9:10	**Opening (Blauwe zaal)**	
9.10–10.00	Keynote lecture (Blauwe zaal): **Max Kinateder (p. 25)**	
	Session A (Room 4)	**Session B (Room 5)**
10:05–11:15	Christina Mayr (p. 28) Ahmed Syed (p. 30) Tobias Kretz (p. 32)	Martyn Amos (p. 29) Emiliano Cristiani (p. 31) Matteo Butano (p. 33)
	Break	
11:45–12:55	Thomas Matyus (p. 34) Mineko Imanishi (p. 36) Steve Gwynne (p. 38)	Angelika Kneidl (p. 35) Michael Spearpoint (p. 37) Adrien Gregorj (p. 39)
	Lunch	
13:55–15:05	Kei Yoshida (p. 40) Paul Geoerg (p. 42) Nikolai Bode (p. 44)	Giuseppe Vizzari (p. 41) Jun Zhang (p. 43) Asim Siddiqui (p. 45)
	Poster session (Senaatszaal)	
16:05–17:15	Sina Feldmann (p. 46) Thomas Chatagnon (p. 48) Geert van der Vleuten (p. 49)	Carl Kjaergaard (p. 47) Evandro José da Silva (p. 57) Jakob Cordes (p. 58)
17:30	**Group picture and Drinks**	

Topic: modeling and simulation (blue)
Topic: laboratory and/or real-life experiments (pink)

Coffee breaks and lunches will be served in the Senaatszaal and Voorhof areas.

Thursday, 29th of June

8:40–9:10	**Coffee & Tea**	
9:10–10:00	Keynote lecture (Blauwe zaal): **Denise McGrath (p. 50)**	
	Session A (Room 4)	**Session B (Room 5)**
10:05–11:15	Pavel Hrabák (p. 52) Rainald Löhner (p. 54) Simon Rahn (p. 55)	Krisztina Konya (p. 53) Enrico Ronchi (p. 56) Bilal Farooq (p. 59)
	Break	
11:45–12:55	Claudio Feliciani (p. 60) Benoit Gaudou (p. 62) Peter Lawrence (p. 64)	Armin Seyfried (p. 61) Ezel Üsten (p. 63) Milad Haghani (p. 65)
	Lunch	
13:55–15:05	Leo Willem Menzemer (p. 66) Wei Xie (p. 68) Jack Suddaby / Capucine-Marin Dubroca-Voisin (p. 70)	Anna Sieben / Tom Postmes (p. 67) Rabia Kodapanakkal (p. 69) Anne Templeton (p. 71)
	Poster session (Senaatszaal)	
16:00	**Social event: guided city tour 's-Hertogenbosch (includes bus transport and drinks)**	
19:30	**Social dinner: Eindhoven, Radio Royaal**	

- Topic: modeling and simulation (blue)
- Topic: psychology, behavioral science, and VR research (green)
- Topic: applications and crowd management (yellow)

Social dinner: Radio Royaal, Ketelhuisplein 10, 5617 AE, Eindhoven - 19:30.

The restaurant is in the Strijp-S neighborhood, 20 minutes on foot from the city center. A bus will drive participants back to the center at the end of the event.

Friday, 30^{th} of June

8:40–9:10	**Coffee & Tea**	
9:10–10:00	Keynote lecture (Blauwe zaal): **Daniel R. Parisi (p. 72)**	
	Session A (Room 4)	**Session B (Room 5)**
10:05–11:15	Caspar Pouw (p. 73) Francesco Zanlungo (p. 75) Juliane Adrian (p. 76)	Céleste Richard (p. 74) Yan Feng (p. 77) Arco van Beek (p. 78)
	Break	
11:45–12:55	Iñaki Echeverría (p. 79) Ashish Verma (p. 81) Tao Chen (p. 80)	
13:00	**Closing words**	
	Lunch	

- Topic: modeling and simulation
- Topic: psychology, behavioral science, and VR research
- Topic: laboratory and/or real-life experiments

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Abstracts

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Burning down the silos: Embracing limitations in interdisciplinary research

Max Kinateder[1, 2]
[1]National Research Council Canada
[2]Carleton University

Pedestrian Evacuation Dynamics (PED) is an interdisciplinary field that studies how people move as a crowd. In this presentation, I will discuss the challenges and promises of working interdisciplinarily and hope to present ways forward to overcome silos. PED touches on questions covering physics, mathematics, architecture and design, as well as psychology and other biological and social sciences. Yet despite its relatively long history – after all, Gustave Le Bon wrote about crowd psychology in the 19th century [1] – only recently have researchers to develop a common vocabulary [2]. While this was an important step to give researchers in an interdisciplinary field a glossary of terminology and to "burn down the silos", there is still no agreed upon definition of what constitutes a crowd. While some definitions refer to crowds as "a multitude of individuals moving in the same place at the same time.", other definitions differentiate between physical and psychological crowds. Physical crowds refer to a large group of people that are gathered closely together, such as commuters waiting at a train station. In a psychological crowd people share a social identity. Typically, psychological crowds are characterized by increased coordination and communication, shared social norms, and a preference for people be in close physical proximity. A commonly named example for a psychological crowd are fans at a sporting event. Both definitions are very useful; the former provides means to describe quantitative boundary conditions of pedestrian movement, the latter points to the observation that psychological states can influence physical movement.

Interdisciplinarity and diversity in general is a strength in research [3]. Fortunately, PED benefits from the varying approaches and methods from a range of fields. While each discipline contributes their unique perspectives, there is still a risk of "silo-ing", given the varying histories, quality criteria for research, and jargon [4], [5]. Scientific silos mean that it is harder to communicate findings across disciplines and increases the likelihood that results are not seen outside their own disciplines. A good example of this, are the contributions from of psychologists and engineers. Very broadly speaking, crowd movement researchers in psychology tend to focus on individuals and how they interact with the people around them. This makes sense given that the local interaction between pedestrians lead to global patterns of motion. Their goal here is to identify the "rules of engagement" between neighbours in a crowd and how individuals coordinate with each other (Figure 1) [6]. Conversely, traditional engineering PED research tends to look at pedestrian movement from a systems perspective. Here, it is important to describe pedestrian movement at an aggregated or global level (Figure 1). The most obvious example of this perspective is the fundamental diagram, which describes the relationship between movement speed and density [7]. Other examples include lane formation, faster is slower effect etc.

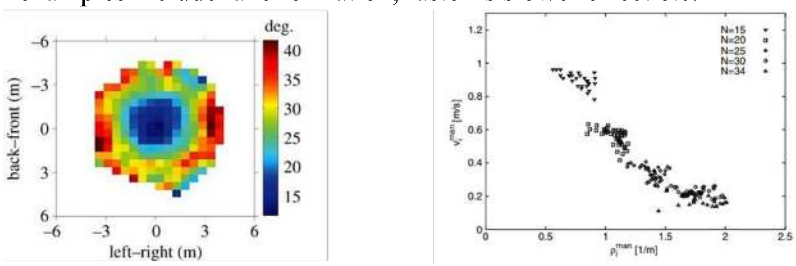

Figure 1: Examples of studies on pedestrian dynamics. Left: A heatmap showing the average alignment in heading of pedestrians with their neighbours in a crowd (reproduced from [8]). Right: The fundamental diagram, describing the relationship between speed and density in pedestrian movement (reproduced from [7]).

A common research taxonomy in PED is needed for researchers who need to assess work outside of their own field. Empirical sciences, such as psychology, typically refer to the "objectivity, reliability, and validity" of a method, whereas engineering-oriented disciplines like evacuation modelling require "verification and validation" (see for a detailed discussion [4], [9]). Readers of empirical research publications, may want to understand how generalizable and reproducible findings are. The latter in particular can be difficult to understand given the inherent uncertainty of empirical data, and often requires relatively large amounts of data to reliably detect evidence for a certain effect. Unfortunately, psychology and many other empirical sciences have disregarded basic requirements for empirical studies (e.g., basing sample size estimations on power analysis [10], [11]) for decades, with the results that many "seminal" findings can not be replicated [12]. This "replication crisis" encouraged psychologists and others to slowly embrace Open Science practices (e.g., sharing data and code publicly, pre-registration of studies, etc.). It can be argued, that reproducibility of results is a particularly tough challenge in PED (e.g., in field settings).

So how does one generate reproducible research on PED? One crux is that any empirical method needs to trade off experimental control, ecological validity, and the generalizability. Ecological validity refers to the degree to which a model is representative of the real world [13]. For example, if we take a look at data from real world events, we can assume high ecological validity. However, it can be hard to transfer findings from one context to another (low external validity) and there is little control over the events that are being observed (low internal validity). Low external and internal validity is necessary for causal inferences and generalizability in empirical research. Further, replication of field observations is rarely possible. Closely controlled laboratory environments allow for looking into fine grained details of pedestrian dynamics and to test specific hypotheses; however, laboratory scenarios can be too artificial and the simulated conditions not realistic enough (low ecological validity; see [9] for an extensive discussion). The proposed solution to this conundrum, is to embrace both approaches. Uncontrolled real-world data are needed to benchmark models and to identify phenomena. Controlled laboratory studies are needed to explore and quantify the underlying mechanisms of these phenomena. No research method is without limitations. By embracing and clearly communicating what these limitations are, researchers can contribute to burning down the silos.

Bibliography

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Estimating pedestrian flows using route distributions and sparse counting data

Christina Maria Mayr[1,2] and Gerta Köster[1]

[1]Department of Computer Science and Mathematics, Hochschule München University of Applied Sciences, Munich, Germany
[2]Department of Informatics, Technical University of Munich, Garching, Germany

At the metro station Müchner Freiheit in Munich, congestion occurs before and after soccer matches when many fans take the shortest route to get from the bus station to the metro. Especially in the area of escalators and elevators, this can lead to jamming, which poses a safety risk. Fortunately, the metro station offers multiple alternative routes to which fans could be rerouted. Hence, we investigated in a previous study, with the help of an online survey [1], how app messages need to be designed so that as many fans as possible take a detour that is communicated using a mobile application. However, it remains unclear how the app messages affect the safety risk and the travel comfort of the fans. In this study, we investigate how flows, and thus safety risk, change when soccer fans receive route recommendations via mobile applications. Since we cannot measure the flows directly in the field, we estimate the flows using route distributions from our online survey [1] and passenger counts collected in a field study, see Fig. 1. We first present the setup and results of the field study. Based on this and the results from our online survey [1], we estimate the unknown flow assuming a balance of flows. Our results show that the change in flow, and thus the safety risk, depends on how the app message is designed. The change in flow also depends on the unknown number of people using a particular side entrance. This shows that we can find a realistic range for the change in flow despite incomplete measurement data, but that further measurements are necessary for accurate predictions.

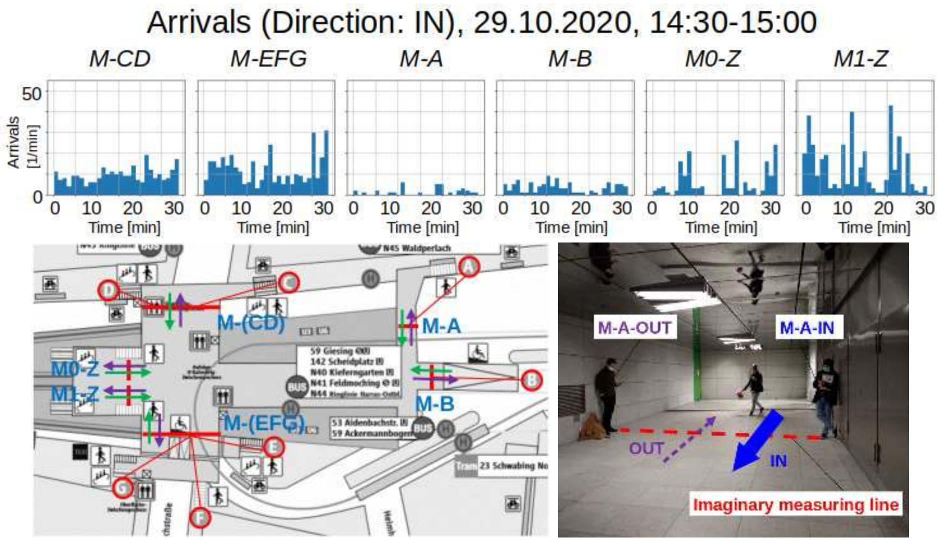

Figure 1: Counting passengers at the metro station Münchner Freiheit in Munich. Bottom, left: We counted arrivals at six imaginary measurement lines in the intermediate floor that connects the surface level (bus) with the underground (metro). The original floor plan can be found online [2]. Bottom, right: Students count pedestrians for each direction individually. Top: The occupancy varies: fewer people use the entrances on the right (M-A, M-B).

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

A dynamic state-based model of crowds

Martyn Amos[1], Steve Gwynne[2], and Anne Templeton[3]

[1]Northumbria University
[2]Movement Strategies
[3]University of Edinburgh

As a discipline, crowd science has acknowledged the need to understand the *nature* of human collective phenomena before trying to *explain* them, and a number of attempts have been made to specify and classify different *crowd types and behaviours* [1]. However, these *typologies* are often partial, over-fitted to a specific crowd type, or use arbitrary and/or subjective labels for behaviours of complex origin (for example, "panic"). Moreover, they tend to be relatively inflexible, and do not reflect the fluid nature of crowd behaviour (and how this might influence the crowd's structure and impact over time). In this paper, we present an alternative to the typology approach; a *dynamic, state-based model of crowds*, structured around an *assembly-action-dispersal* framework derived from the "convergence-task-divergence" life cycle [2]. Our model, which draws on the statechart formalism from computer science, is relatively objective, can capture the dynamic evolution of a crowd over time, and allows for the emergence (and parallel description) of an unlimited number of spontaneous sub-groups within a crowd (by "forking" an existing instance of the model to create a new "child" instance). Importantly, our model focuses largely on *observable* features of crowds, makes no assumptions about underlying psychological factors or individual motivations, and lends itself to codification in computer simulations. The model is sufficiently rich to capture macro-level *descriptions* of crowds, but may also be easily augmented to provide more fine-grained *simulation control* (for example, by adding probability distributions to state transitions. We describe the basic model, explain its operation, and discuss its possible application across a range of scenarios.

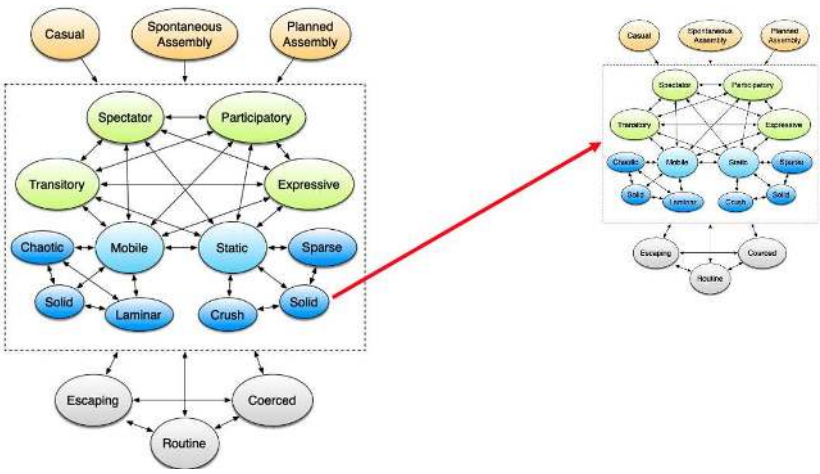

Figure 1: Dynamic state-based model of crowds, showing assembly (yellow), rationale (green), physical configuration (blue) and dispersal (grey) states, with a depiction of how the model may be "forked" to represent a new sub-group in a crowd.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Benchmarking crowd management interventions via highly accurate RGB pedestrian tracking

Ahmed Syed[1], Alessandro Corbetta[2], Sumesh P Thampi[3], and Mahesh V Panchagnula[4]

[1,4]Department of Applied Mechanics, Indian Institute of Technology Madras, India
[2]Department of Applied Physics, Eindhoven University of Technology, The Netherlands
[3]Department of Chemical Engineering, Indian Institute of Technology Madras, India

Continuous urbanization demands better infrastructures such as bus stations, train stations, and airports. Over the years, the number of commuters increased, and these numbers go much higher in the coming decades therefore managing crowds in these existing infrastructures is a challenging task. Placing interventions to steer the crowd is one of the effective crowd control strategies. Yet the quantitative analysis of these steering flows for effective crowd management is still unclear.

Figure 1: Pedestrians entering the station waiting hall being steered by police officer towards the exit. The deep learning algorithm (RETINA FACE) automatically detects pedestrians(green box), and the yellow line represents pedestrian height.

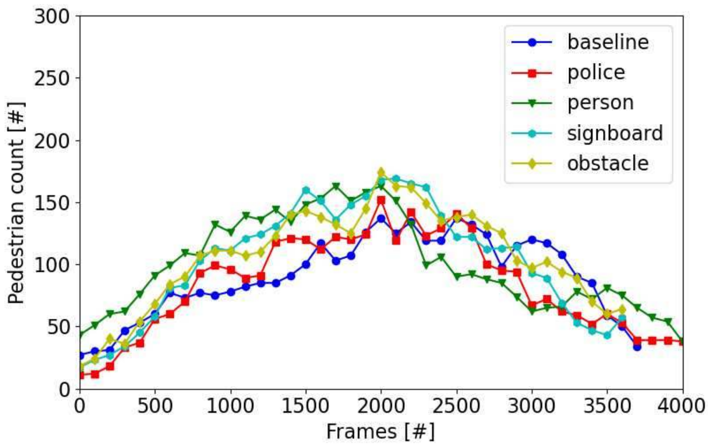

Figure 2: Pedestrian counts as a function of the different steering measures.

In this study, we investigate the effectiveness of the interventions (Passive: one with the obstacle and the other as a signboard. Active: one by a steward in a reflecting jacket and the other as a police officer) in real crowd flows using deep learning algorithms (Retina face) for quantitative analysis (Fig. 1). All the scenarios are video recorded on different mornings in one of the busiest local train stations of Chennai city, India (100K+ passengers/day). We developed an algorithm that correctly localizes the position of the pedestrian in 3D space leveraging on the position of the face and height estimate. By analyzing the pedestrian count (Fig. 2), trajectories and velocities, we found that the active policeperson intervention resulted in better crowd evacuation efficacy.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

An All-Densities Pedestrian Simulator Based on a Dynamic Evaluation of the Interpersonal Distances

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In this talk we deal with pedestrian modeling, aiming at simulating crowd behavior in normal and emergency scenarios, including highly congested mass events. We are specifically concerned with a new agent-based, continuous-in-space, discrete-in-time, nondifferential model, where pedestrians have finite size and are compressible to a certain extent, cf. [1, 2]. The model also takes into account the pushing behavior appearing at extreme high densities.

The main novelty is that pedestrians are not assumed to generate any kind of "field" in the space around which determines the behavior of the crowd. Instead, the behavior of each pedestrian solely relies on its knowledge of the environment and the evaluation of interpersonal distances between it and the others. The model is able to reproduce the concave/concave fundamental diagram with a "double hump" (i.e. with a second peak) which shows up when body forces come into play, see Fig. 1.

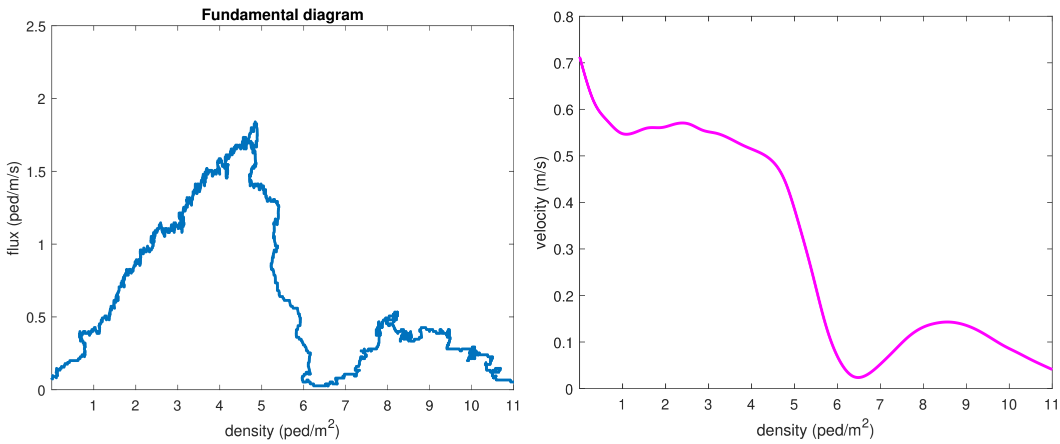

Figure 1: *Left*: flux as a function of density. The double hump is visible and it can be compared with that reported in [3]. The second hump is clearly due to the pushing behavior, and it vanishes around 11 ped/m^2. *Right*: velocity as a function of density. Double hump is visible here too.

We present several numerical tests (some of them being inspired by the recent ISO 20414 standard [4]), which show how the model can reproduce classical self-organizing patterns.

The reference paper for this research is [2].

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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What can be learned from (public) Running Result Data?

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PTV – Planung Transport Verkehr GmbH

Marathons and other public running events have become popular and common. Results are published on the web. In this way each week dozens, if not hundred data sets become newly available. Data often include personal attributes like age and often gross as well as net finishing time are documented, gross time being the time between start signal and finishing and net time being the time between crossing the start and the finish line.

The difference between both times gives the time after start signal when the runner has crossed the start line. From that one can easily calculate the flow of runners over the start line. For this contribution the data of one event – Ref [1]- has been exploited. The flow over time has a characteristic shape – Figure 1 left – which allows to draw general conclusions and can be used for comparison with simulation results for which two examples are given in Figure 1 right.

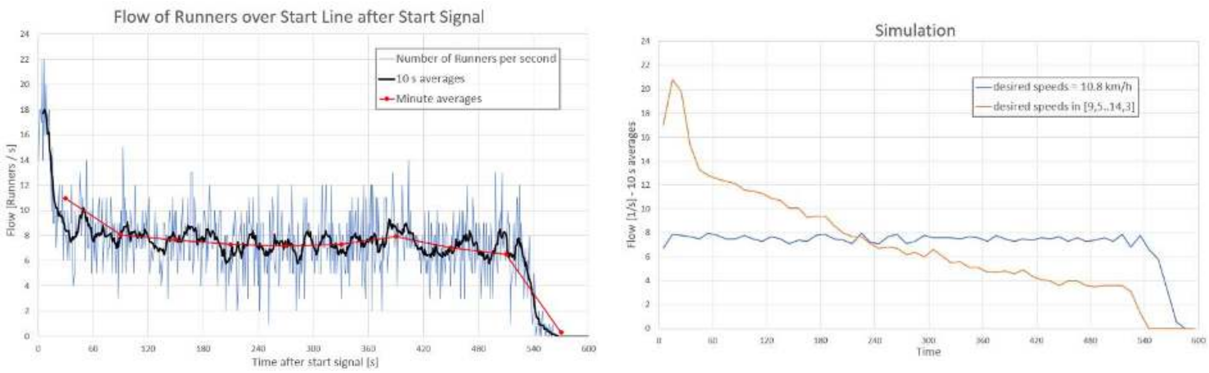

Figure 1: Flow of runners over start line vs. time, real (left) and simulated (right).

Interesting with the empirical data is that the flow is nearly constant for ~90% of runners despite the running times of the middle 90% of runners stretch over an average speed equivalent from 2.3 to 4.0 m/s. This means that either runners at the start intuitively coordinate their speeds (and desired speeds as well?) or that the variation in speeds is compensated by a variation in density such that the resulting flow is constant.

In the simulation the sharp peak in the beginning could be reproduced when (simulated) runners get assigned a variation of desired speeds ordered with a linear dependence on distance to the start line. Whereas the flat plateau of the flow so far required that everyone was assigned the same desired speed.

In the full contribution further properties of the existing empirical data will be discussed and it will be discussed which opportunities future, extended data taking at running events could hold. Third, possible modifications to the Social Force Model or requirements for models in general will be discussed that could lead to a reproduction of the observed evolution of flow over time.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Mean-Field Games Modeling of Anticipation in Dense Crowds

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It has been established that, following the differentiation of [1], when studying how pedestrians move, it is possible to distinguish among the *strategic* level, describing the goal of the travel, where a certain individual is headed; the *tactical* level, or which route will be chosen to reach the final destination; and finally the *operational* level, the actual trajectory along the chosen route. We recently focused on the operational aspects of pedestrians' motion in dense crowds, by studying how individuals react to the presence of a moving cylindrical intruder [2]. In particular, we used the real-world data collected

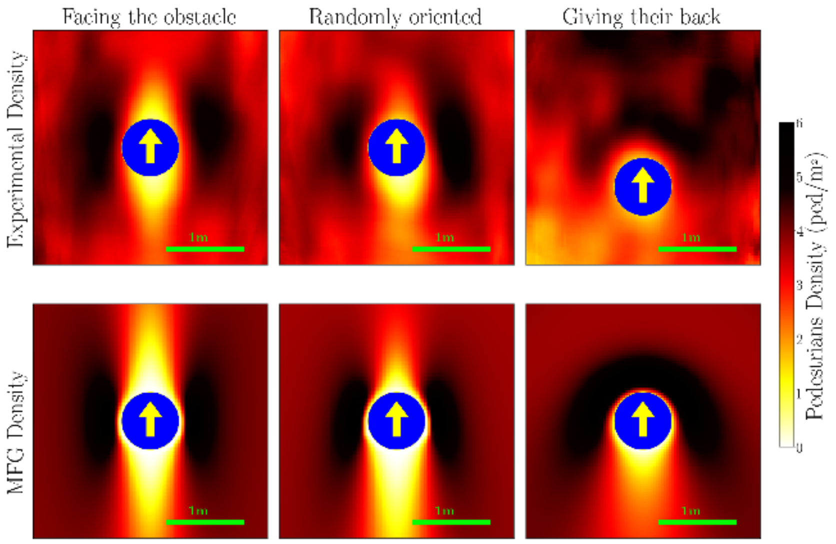

Figure 1: Comparison between experimental data (top row) of a dense crowd ($3.5ped/m^2$) being crossed by a cylindrical intruder (here seen from above moving upwards) for three different configurations (facing the intruder, randomly oriented and giving their back to it) and Mean-Field Games simulations (bottom row) performed with different values of anticipation discount.

by A. Nicolas et al. [3], where such situation was reproduced in a controlled environment, in three configurations: with individuals facing the obstacle, being randomly oriented or giving their back to it, each case entailing a different awareness about the obstacle. In [2] we have successfully treated the first of these three configurations by means of a minimal model based on Mean-Field Games. Here we claim that, as we can see from the second and third columns of Figure 1, we can account for the other two configurations. We do so by using the same model simply by adding a term discounting agents' foresightedness, effectively shortening their reaction time and causing them to deal with the arrival of the obstacle less optimally, to the point where, as the third column of Figure 1 shows, they are pushed along by it. The model we present here correctly reproduces the different experimental configurations only by means of one parameter, however remaining minimal in terms of complexity. We believe that MFG is therefore not only a valid technique to simulate, but it is also the right theoretical framework to have a better understanding about how pedestrians move in crowded spaces, at least in situations where long-term anticipation plays a crucial role.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Analyzing the Effects of a Column in front of a Bottleneck in a Transportation Infrastructure Using Real-World Trajectories

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Based on simulation studies [1] showing that the flow through a bottleneck increases when a column is positioned in front of it, several experiments have been conducted in recent years (an overview can in be found in [2]) that partially confirm this hypothesis. Since these studies were done with experiments under laboratory conditions, we investigated whether similar phenomena also occur in a real environment for bi-directional flows and a wider (3.9m) bottleneck. As observation area, a railway station in the center of Vienna (Austria) was chosen which is directly connected to a shopping mall. At the ceiling in front of the door of the station, at the transition from the station to the mall eight video-based counting sensor were mounted also covering the doorway. A column (70cm diameter) was set up at three different positions to investigate its influence on the pedestrian flows. Additionally, the initially white cover of the column was replaced with an arrow design, in order to see if this would stimulate more people to pass the column on the right.

In total, five scenarios were defined: 1) basic scenario without change, 2) white column placed centrally in front of the exit at a distance of 3.8m, 3) white column centrally at a distance of 1.6m, 4) same column position as in scenario 3 but with arrow design and 5) column with arrow design moved 70cm to the right from the previous position.

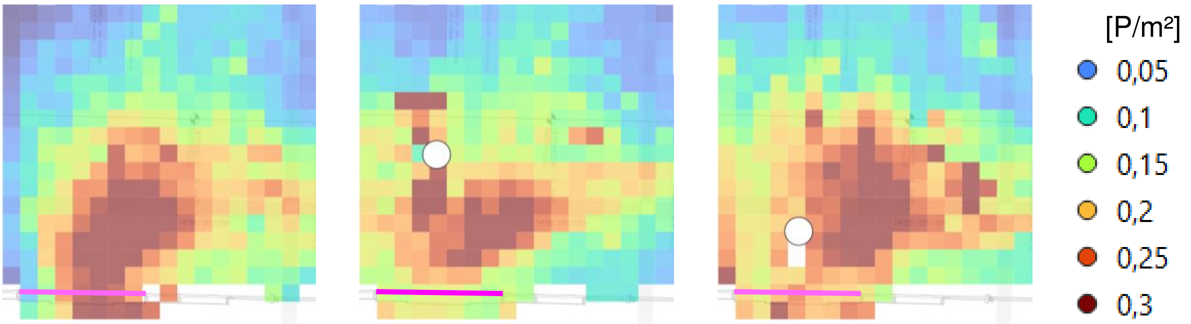

Figure 1: Densities [P/m²] of the base scenario (left) compared to scenario 2 (middle) and scenario 3 (right). The white circular areas indicate the position of the column. The magenta line marks the position of the door.

For the analysis, the recorded trajectories of a whole day were evaluated, comprising the spatial distribution of the routes, the person densities (see Figure 1), the fundamental diagrams, conflicts between pedestrians and the distributions of the average walking speeds and of the distances within a 3.9m x 5m rectangular zone in front of the door.

Exemplary results of the data analysis include: 1) No significant differences between the white column and the column with the arrow design can be measured. 2) The mean walking speeds are reduced by about 5% in all column scenarios compared to the base scenario.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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DIN 18009-2 – a new German standard on evacuation simulation

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After more than eight years of intensive standardisation work, the second part of the German DIN 18009 standard on "Simulation of evacuation and personal safety" was published in August 2022. The DIN 18009 series deals with fire protection engineering for Germany. The first part "Principles and application rules" was published in 2016, with further parts describing standards for smoke simulation and safety concepts to follow.

DIN 18009-2 [1] standardises the performance-based approach for conducting evacuation simulations. It builds on earlier pre-standards such as the German RiMEA Guideline [2] as well as international standards such as ISO/TR 13387-4,16738BSI PD 7974-6 (British) or the CFPA-E Guideline No. 19.

It is a milestone for the simulation community as it emphasises the growing importance of simulation models in the building design process and in fire safety. It places new requirements on existing models and evaluation procedures and gives modellers and authorities guidance on how to use simulation as a useful tool in their projects.

The new standard provides a step-by-step approach to defining scenarios and performance criteria, selecting the simulation model, and documenting and analysing the results (see Figure 1). Various safety criteria, such as total evacuation time and congestion analysis, are introduced to evaluate and interpret the results.

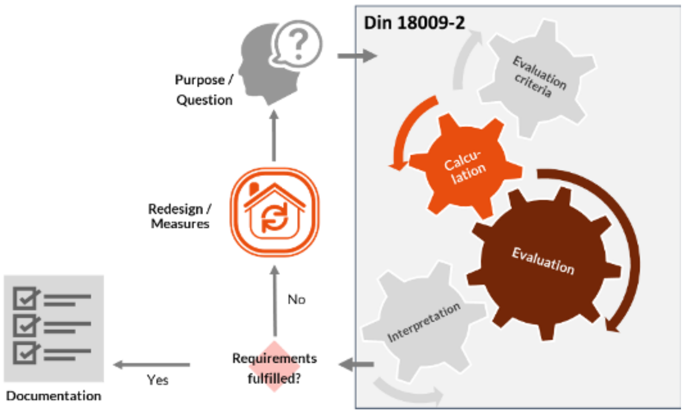

Figure 1: Overview on the procedure of the performance-based approach based on the new Standard.

While the required evacuation time can be analysed by a simple comparison of ASET (Available Safe Egress Time) - RSET (Required Safe Egress Time), the standard gives engineers more leeway when analysing congestions: In the current version, no specifications are provided for the evaluation of congestions, since congestions are not inherently dangerous and even occurs in buildings that comply with building regulations. The standard makes it the user's responsibility to assess the congestion in the context of the use case. To support the user, the standard provides several metrics, such as duration, location and size of congestion, delay time through congestion as well as congestion density.

The paper gives an overview of the new standard and discusses the open issues that do not provide clear guidance to modelers in terms of congestion analysis. We also outline what knowledge is needed from a modelling perspective to be able to perform standard-compliant analyses in the future.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Placing Large Obstacle in the Centre of Pedestrian Intersection: Introduction of "Pedestrian Roundabout"

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In facilities hosting large crowds, such as railway stations, stadiums, and convention centres, visitors in transit have different destinations. Pedestrian flows are therefore complex, unlike building evacuations, where occupants move in single direction. When multiple flows cross, they can easily become stacked because of the sudden increase in density and the difficulty of avoiding other people coming from different directions. Moreover, walking in a disordered crowd is mentally stressful and even poses the risk of striking others.

Solving such congestion is essential for flow efficiency, safety, and user comfort. We recently developed the "Pedestrian Roundabout" to optimize complicated flows at intersections. This paper reports the mechanism and effects of it. In a Pedestrian Roundabout, a large obstacle several meters in diameter is placed in the centre of a pedestrian intersection and pedestrians are required to walk in one direction around it like an automobile roundabout.

To determine the effects of the placement of such an obstacle on the crowd flow characteristics and detailed walking behaviour at a crossing point, we performed two full-scale laboratory experiments, one in 2018 with 48 participants and another in 2019 with 96 participants. In the experiments, two or four groups of paritcipants walked simultaneously to the oder side of the crossing in that a large obstacle is placed by detouring it. The shape of the obstacle, the density of pedestrians, and the constraint of walking direction were varied in the experimental conditions to determine effective factors for the optimization of traffic flow.

The results indicate that such an obstacle optimizes walking speed reduction. Furthermore, constraining the walking direction reinforces this effect and the trajectories became smoother due to decreases in detouring around others (Figure 1). The roundabout changed the merging angle when entering the circulation into sharp. Consequently, the relative walking speed to others became smaller that makes easier to predict the movement of others. It suggests the size of the obstacle must be large enough to gain the flow optimisation effect. Moreover, according to the questionnaires after each trial, the participants felt it was easier to walk with the roundabout than a normal crossing.

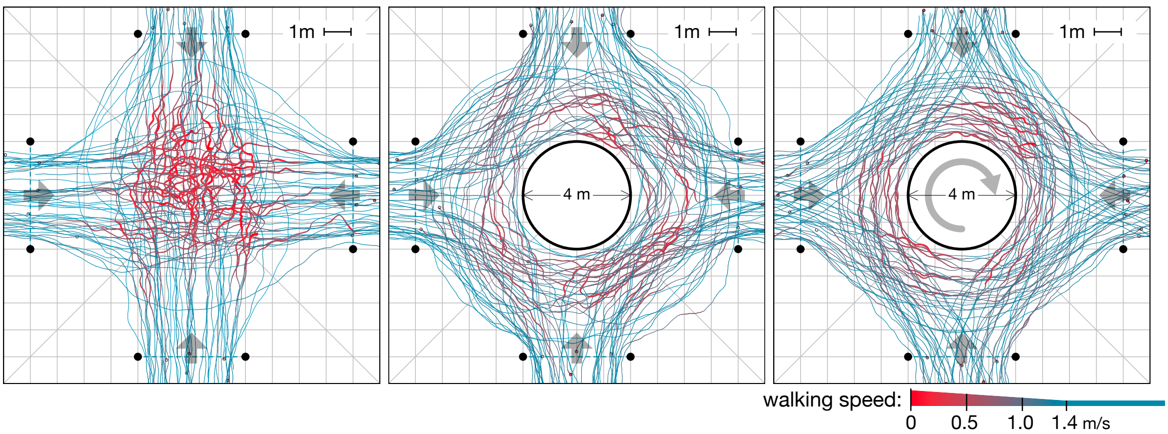

Figure 1: Walking trajectories in an experiment trial colourised by reduction in walking speed reduction. (Left: Normal crossing / Centre: With obstacle / Right: With obstacle and one-way constraint)

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Comparative analysis of two evacuation simulation tools when applied to high-rise residential buildings

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Currently there are various emergency evacuation simulation tools available, each with varying levels of sophistication and differing capabilities [1]. It is not unexpected that investigating the same scenarios using the different tools might not give the same outcome. This paper illustrates how two simulation tools can be setup to give similar results for the evacuation of high-rise residential buildings that have differing number of storeys, with one or two stairs, and different stair widths.

Two simulation tools are used, namely Pathfinder and Evacuationz. Both represent individual agents with their own characteristics such as unimpeded walking speed and pre-evacuation delay. In this work agents are either assumed to begin their evacuation immediately or have pre-evacuation delays that depend on whether they are deemed asleep, the type of notification system, etc. The two tools differ in how they deal with the building geometry (Fig. 1). Movement in Pathfinder is calculated across continuous planes located at each floor level using a triangulated mesh to represent occupiable space and the paths across it. Conversely, Evacautionz is a node network tool that uses a hydraulic flow approach [2] to movement.

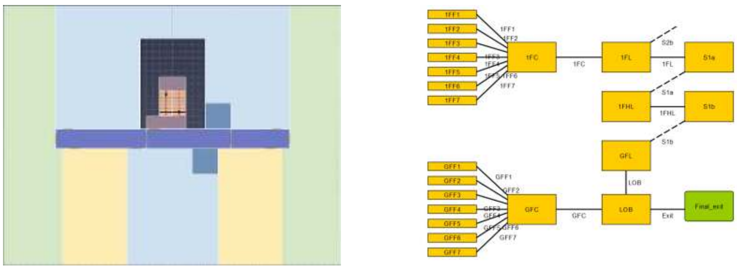

Figure 1: Geometrical representation of a stair and rooms: left – Pathfinder, right – Evacuationz.

The default agent movement distance within a node in Evacautionz results in much longer times than predicted by Pathfinder. When walking down stairs, Pathfinder's agents follow an inner line whereas Evacautionz assumes a longer path. In tall buildings this difference accumulates leading to divergent predicted total egress times. Once the Evacautionz path is adjusted to mirror that of Pathfinder then results are very similar. However, when the two tools are used to include the impact of slower agents that represent those in wheelchairs that may block the movement it is found that the results are different. Whereas Pathfinder's continuous geometry representation means agents are precisely located in the space, Evacautionz has to assume that the agents are located in the same node but their relative position is unknown. Evacautionz cannot tell which agent is behind the other and therefore assumes blocking always occurs. Differences are further exacerbated when agents transfer between nodes as the order in which transfer takes place is random so that blocked agents can effectively overtake blocking agents.

Different simulation tools can give similar results, although depending on their capabilities and the specific objectives there is a limit to how far equivalent outcomes can be obtained. It is important that users be knowledgeable about the capabilities of the tools and be competent at using them to make appropriate input adjustments. Simply using a tool in its default configuration may not be the optimal solution.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Methodology Developed for Field Observations of Large Events During the Pandemic

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The Events Research Programme (ERP) was a UK-based study undertaken in 2021[1]. This involved industry, government and academic research partners investigating the risk of virus transmission at events to inform future government policy. GHD staff conducted a behavioural study involving 21 pilot events in the UK between April-July 2021. Data was collected on how non-pharmaceutical interventions (such as social distancing and the use of face coverings), influenced attendee activities and might enable people to attend future events safely. This paper focuses on the methodology employed and how the techniques were able to operate across different contexts and conditions (see Figure 1).

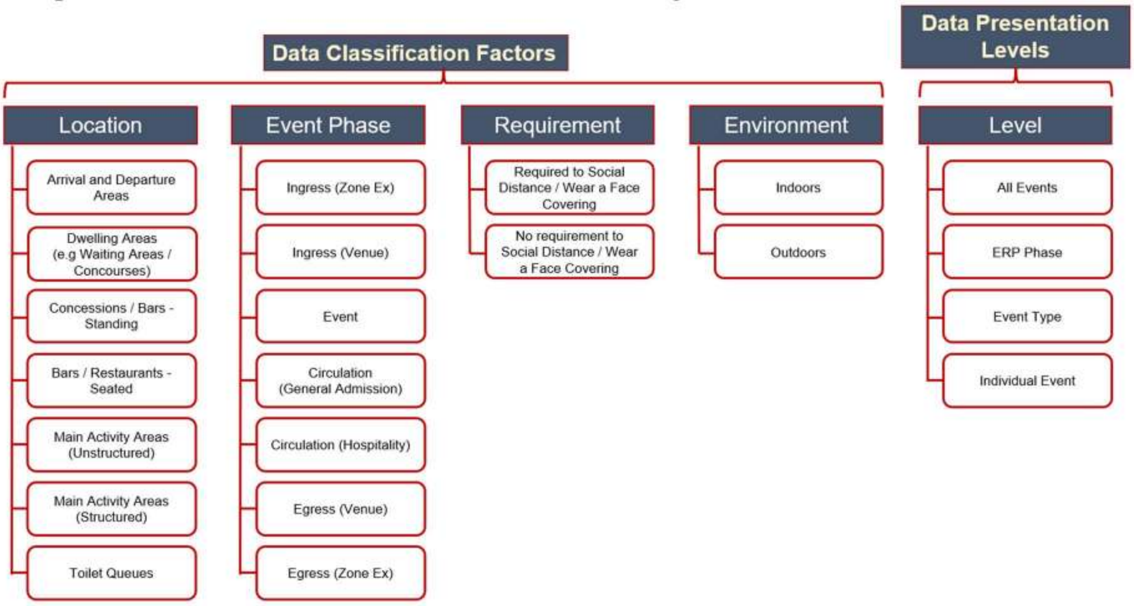

Figure 1: Key variables examined in data collection process.

Data were captured at each event from sources including video, photos, in-person field observations, architectural drawings, ticket admissions, and concession sales. This mixed methods approach captured qualitative and quantitative data in an integrated manner – identifying event timelines and structuring the analysis of the quantitative datasets collected. These qualitative findings also provide an underpinning for the more detailed quantitative approaches – ensuring that they captured locations/times of value and supported the development of behavioural dictionaries, enabling actions to be operationalised during the data collection process. For each event, footage was categorised by Location, Event Phase, Requirement and Environment (see Figure 1). Data included contact distances (derived from density measurements) and the wearing of face coverings. The levels observed were categorised by the factors identified above and supported by associated qualitative insights.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Asymmetries in group-individual collision avoidance due to social factors

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A few recent studies have focused on the dynamics of small social groups and on its effect on the crowd flow, some of them studying how the group structure and velocity depends on social relation and interaction intensity, and others studying how the surrounding environment affects the shape and motion of the group [1, 2]. In order to improve our understanding of the role of groups in the overall crowd dynamics, it is also necessary to study the specifics of collision avoidance between groups and individuals, possibly focusing on the aforementioned group properties (such as social relationship and interaction intensity). Our recent works have shown that collision avoidance between groups and individuals is more pronounced, when the group has a stronger social bond, which may be characterized by the social relations (e.g. couples) or intensity of social interaction (e.g. engagement in conversation) [3, 4, 5].

However, such inferences are drawn based on an analysis performed studying only relative distance between the group and the individual, which does not allow determining how much each of the involved parties (i.e. the group and the individual) contribute to such collision avoidance. One may intuitively expect the group to be absorbed by its own social interaction and thus to be less responsive to the pedestrians around it, which leads such individuals to avoid more actively so as to compensate (or possibly that such behavior is a result of a "social norm"). In order to test this hypothesis, this study analyzes natural trajectories of uninstructed pedestrians collected in a straight corridor from the publicly available DIAMOR data set.

In particular, we focus on frontal encounters between 2-people groups and individuals and quantify the contribution of each party to collision avoidance in terms of its deviation from its intended trajectory. In doing that, we first identify the point of encounter of the groups and individuals (i.e. the point on their trajectory, where they are closest) and use their velocity 4 meters prior to that for estimating their intended trajectory (approximated as a straight line). The maximum distance between this intended trajectory and the observed trajectory can be interpreted as the *lateral deviation* of the pedestrian.

We observed that group members deviate significantly less than individuals during frontal encounters. Additionally, using available annotations from the DIAMOR dataset, we analyzed the effect of the intensity of interaction of the group members (ranging from 0, no interaction, to 3, high level of interaction) on the collision avoidance dynamics. The difference between individuals and group members' deviation was found to be more pronounced when the level of interaction of the group is high, while for lower levels of interaction, the dynamics get more similar. Finally, we found that higher levels of interaction consistently lead to larger deviations in the encountered individuals.

We believe that this study will improve our understanding of pedestrian collision avoidance by exhibiting its asymmetry in the case of group-individual encounters, and revealing the effect of social factors. This could in turn lead to enabling the development of more realistic crowd simulators and socially aware autonomous agents.

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Structural Analysis and Topological Manipulation of Visual Influence Networks in Walking Crowds

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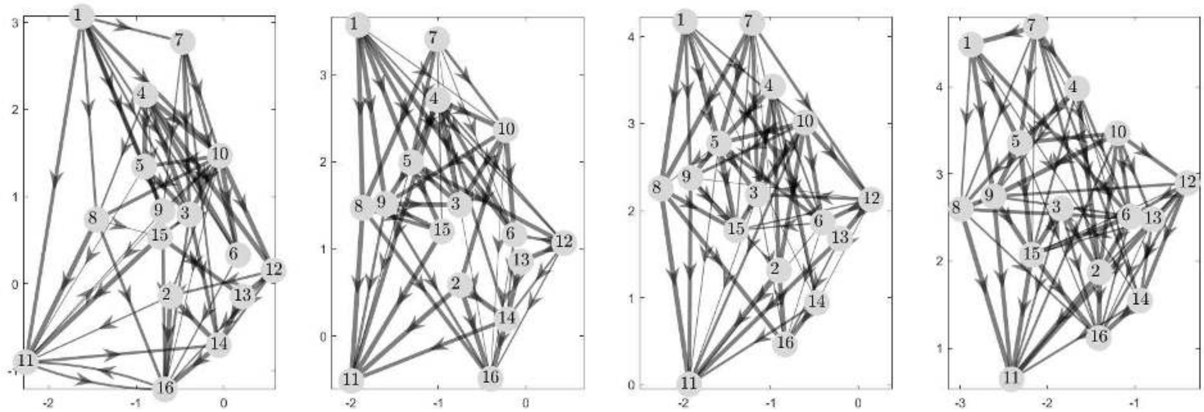

Figure 1: Example snapshots of visual influence networks (N=16). Node positions represent the positions of pedestrians in the crowd (the group mean heading as a vertical axis), and the edge directions and widths represent the leader-to-follower influence and strength, respectively.

Collective motion in human crowds is generated by local visual interactions between neighboring pedestrians. In this self-organizing phenomenon, it has been shown that some individuals play the role of “leaders” who strongly influence the crowd, and scenarios such as emergency evacuation can benefit from strong leadership. However, the underlying mechanism of how one influences others and gains leadership in moving crowds remains to be uncovered.

One way to approach this problem is to reconstruct interaction networks of moving crowds. We employ a spatially-embedded dynamic network representation of interpersonal influence constrained by visual sensory information. We analyzed 15 min of motion-capture data from a human “swarm” experiment (N=10,16,20) in which participants were instructed to walk about the tracking area while staying together as a group. We reconstructed the network every second using Time-Dependent Delayed Correlation (TDDC) (e.g., Fig. 1). Measures of net leadership and accumulated influence (Yoshida & Warren, 2022) produced consistent leadership gradient pattern from the front to the back. We find that leadership strongly depends on spatial position and weakly on personal qualities, with some individuals exhibiting stronger/weaker influence.

Additionally, we introduce an experimental paradigm to alter the network topology in real crowds and study the effects of the manipulation on the macroscopic crowd movements. In this experiment, confederate “leaders” are given instructions about turning direction and timing, and their presence is either unknown or known to the crowd. We investigate whether and how information about heading change initiated by the confederates propagates through a walking crowd, and we assess how uninformed pedestrians adjust their movement. Understanding the network structure and dynamics may help quantitatively explain leader influence.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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A Reinforcement Learning Approach to Environment Exploration and Wayfinding

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Research in the area of pedestrian modelling has started investigating the application of Machine Learning (ML) approaches leveraging the growing amount of data describing pedestrian and crowd behavior (see in particular `https://ped.fz-juelich.de/da/doku.php`, accessed on 31 January 2023). The data driven nature of these approaches, however, makes it difficult to achieve models characterized by the level of *generality* (i.e. applicability to a relatively wide range of situations) achieved by manually defined approaches. Recent results have employed Reinforcement Learning (RL) [1], a particular type of ML approach in which agents situated in an environment explore the potential space of the policies (i.e., agent behavioral specifications) and converge to a specific behavior assuring the maximization of an expected cumulative reward (a feedback signal evaluating the adequacy of agent's behavior in a given situation). In particular, in [2] we proposed a *curriculum* based approach, in which agents were proposed training scenarios of growing complexity, granting both a reasonably fast training and an interesting level of generality and direct applicability of the learned policy. The model focused on *operational level decisions*, although agents were provided with basic information supporting the navigation of simple environments comprising interconnected rooms, but they were not able to choose among alternative paths towards a final goal.

The present contribution builds on the framework discussed in the above cited paper to investigate the possibility to train agents that are able to perceive and exploit environmental information supporting wayfinding. Passages are associated to information indicating if they represent a reasonable way towards a final exit from a scenario, and also if they are to be followed to reach *intermediate* targets. The learning process guides agents to develop a policy leading to the exploration of the environment to reach a set of intermediate waypoints and the final movement target, irrespectively of the specific map of the environment. The contribution will discuss the overall framework, the experimented training process, and the achieved results. In particular, Fig. 1 compares the paths and velocities of an agent employing Unity built-in path planning function (under the assumption that the agent has a complete knowledge of the map of the environment) on the left, and the trajectory produced the learned movement policy on the right.

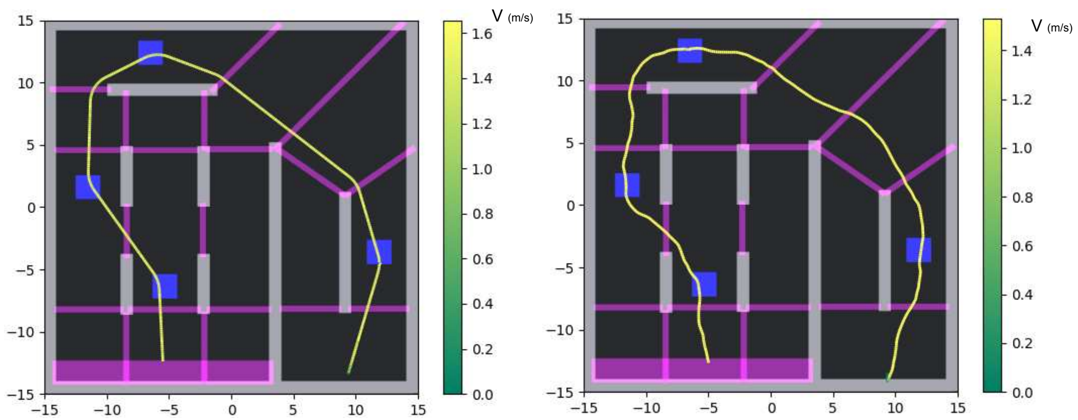

Figure 1: Built-in path planning with complete knowledge (left) and RL agent trajectory (right).

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Together apart: the influence of increased crowd heterogeneity on crowd dynamics at bottlenecks

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Predicting pedestrian egress performance is a crucial element of performance-based design. Yet, capacity estimates and indicators of pedestrian movement usually rely on data from homogeneous crowds, i.e. data that is typically collected from young adults without disabilities. Individual differences in mobility and space requirements (e.g., due to wheelchair use) are often ignored. Consequently, engineering tools cannot fully describe the impact of vulnerable populations on egress performance.

There is anecdotal evidence that pedestrians keep a larger distance from wheelchair users, which could influence fundamental relationships between speed and density [1]. However, the underlying mechanisms are not understood. We tested two potential explanatory mechanisms: perceived vulnerability and perceived required space. That is, will people increase their interpersonal distance to wheelchair users because there is a social norm to be mindful of people who appear vulnerable or because wheelchair users simply appear to take up more space?

We present a study in which three groups of pedestrians with varying perceived vulnerability and space requirement move through a simulated bottleneck. Fig. 1 gives an overview of the study. The *control group* comprised only participants without any additional equipment; in the *luggage group* and the *wheelchair group* two participants in the center of the group were either carrying suitcases (increased space requirement but no increased vulnerability) or using a wheelchair (increased space requirements and increased vulnerability). Participants were asked to move from a starting position through the bottleneck. Results will be presented from trajectory data [2] and include indicators of pedestrian dynamics such as speed and density.

(a) Wheelchair user (b) Luggage user (c) Trajectories

Figure 1: Example still images from two trials with participants (in circles) using wheelchairs (Fig. 1a) or carrying suitcases (Fig. 1b). In each trial participants moved from a defined start position through a bottleneck; example trajectories (Fig. 1c) of a trial with wheelchair users.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

An Attention Mechanism based Data Driven Model for Crowd Simulation

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Crowd simulation is always a hot topic in pedestrian and evacuation dynamic fields, which has been evolving and developing with the continuous breakthrough of science and technology. Meanwhile, theories and conceptions in other relevant fields are often introduced generating plenty of interdisciplinary approaches and models. Helbing et al. developed social force model by bringing force theory and grain flows theory in physics. The success of Cellular automata in traffic simulation field prompted researches to attempt it for crowd simulation and successfully create the discrete model system. In the era of big data, machine learning algorithms, more specifically deep learning technology is booming and has been widely applied into many studies. Relaying on these technologies, data driven based models are gradually proposed for crowd simulation. For pedestrian behaviour modelling in terms of microscopic scale, researchers developed some data driven models in the lights of neural network and achieved pedestrian movement simulation in some extent. They made a great effort in the design and generation of features representing individual's motion characteristic and decision-making behaviour. The features are usually generated by quantizing the perception individuals received from his/her surroundings including other pedestrians and the boundaries of scenarios and then directly packaged to be inputted into the neural network. While the neural network-based model lacks of interpretability. How the quantized features pass and fuse inside the network and whether the network really has the capability of presenting individuals' decision-making behaviour, like interacting with their surroundings, which is worthy of paying attention to explore. Fortunately, attention mechanism provides an attemptable way for this research.

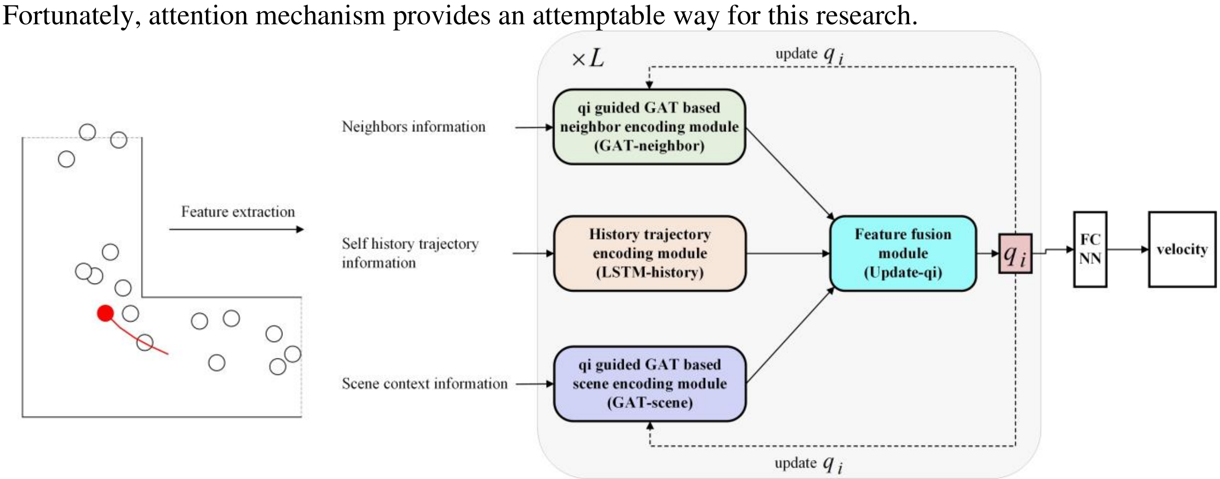

Figure 1: The overview of the proposed attention-based model.

We take advantage of attention mechanism and propose an attention-based model, the overview of which is shown in Figure 1. We describe individual's motion decision-making behaviour from three aspects, the interaction with neighbours, scene context, and history motion trajectory. Accordingly, three basic modules encoding information from the three aspects are established. We introduce graph structure to represent the interaction between individual and his/her surroundings and use Graph Attention Network (GAT) to achieve 'conscious' perception. We successfully apply the proposed model on a right-angle corner scene and illustrated the capability of the proposed model in capturing the interaction between individual with surroundings by visualizing the attention weights outputted from the GAT involved modules.

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Analysis of Long-term Observational Data on Pedestrian Road Crossings at Uncontrolled Locations

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Crossing roads ranks amongst the most dangerous activities for pedestrians [1]. Roads can be crossed at controlled, signalised locations, where traffic lights or zebra crossings regulate the behaviour of all traffic participants, or at uncontrolled locations, where pedestrians typically do not have priority. It is generally acknowledged that pedestrians take risks when crossing roads at uncontrolled locations and that their behaviour on whether to cross or not depends, amongst other factors, on the traffic conditions, such as vehicle speeds and gap sizes between vehicles, and the social context, such as pedestrians being in a group (e.g. [1,2]). Technological advances mean it is now possible to record observational data on pedestrian road crossing behaviour from public roads almost continuously using commercially available sensors. Here, we report on such a data collection campaign in Bristol, UK. We record the movement paths of traffic participants within the field of view of a commercial camera-based sensor (see Fig. 1A). Over April 2022 alone, we detect around 60,000 pedestrian road crossings at one location. We first explore the time series of hourly crossing counts, finding pronounced and regular temporal patterns (see Fig. 1B,C), and we investigate the effect of averaged road traffic conditions (e.g., speeds, gaps between vehicles) and extraneous factors, such as university term dates, on observed counts. We then critically discuss if the accuracy of data collection is sufficient to investigate the behaviour of individuals and to what extent deficiencies in accuracy can be addressed through the volume of data available. Specifically, we seek to determine if the timings of crossings indicate social crossing behaviour, such as groups crossing synchronously or following behaviour. We also attempt to fit individual choice models to the data to predict the timing of pedestrians' crossing. In summary, in addition to the specific findings on road crossing behaviour of our study, a key contribution of our work is a case study for how to work with large-volume, low-fidelity observational data on pedestrian behaviour that is becoming increasingly available.

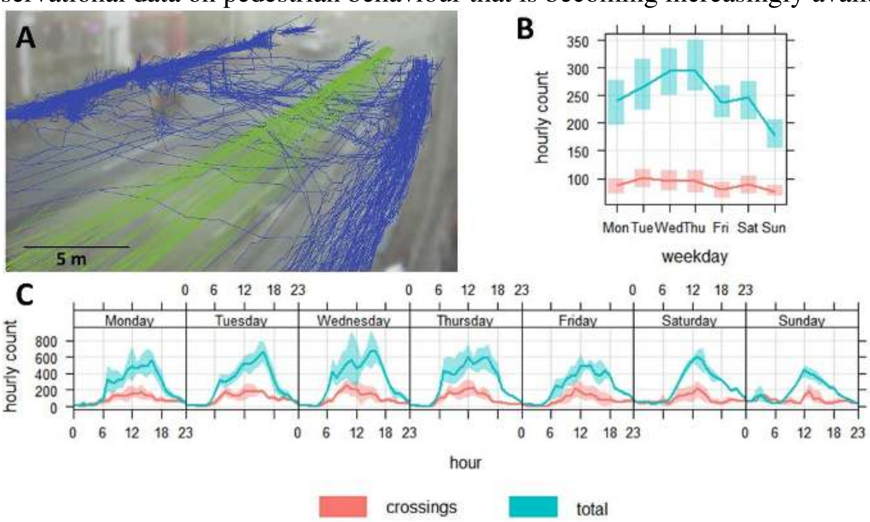

Figure 1: (**A**) pedestrian (blue) and car (green) trajectories captured 8.10-8.20am on 13/10/2022, superimposed onto a camera still image (blurred for privacy). (**B&C**) Averaged weekday patterns in time series for April 2022 of crossings and total pedestrian counts at a reference counting line with bootstrapped 95% confidence intervals.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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The birth of a new BIM standard: from PED 2018 to 2023, new parameters and workflows "going live" for everyone

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Building Information Modelling (BIM) has become the de facto standard for the digital representation of buildings. However, pedestrian modelling tools generally use BIM-based models only to extract geometry, ignoring the full potential they offer to store semantic information, such as occupant model inputs, outputs, and parameters. This study highlights the latest team effort, supported by buildingSMART International (bSI), to expand the BIM Industry Foundation Classes (IFC) Model standard data to support workflows for pedestrian simulation tools. The need for such standardization was initially identified during PED 2018, in discussions between the University of Greenwich (UoG), Accu:rate, Autodesk, and IST GmbH. A strategy paper [1] highlighted the need for this work, which culimanted in a 2 year project called "Model View Definition (MVD) for Occupant Movement Analysis (OMA)" administered by bSI, and developed by a working group of both academic and industrial collaborators. The work has been delivered in 2 phases:

(1) led by the Technical University of Munich, where real-world 'use cases' defined core workflows, and

(2) where UoG has been leading the definition of the workflow parameters to support the established working 'use-cases'. Data requirements have been synchronised with key commercial software vendors and academic institutions and sets of pedestrian parameters and data definitions (see Fig. 1) are now being finalised. This process has been coordinated with multiple pedestrian modelling tools to ensure that the parametric definitions will cover the core workflows supported by the software tools. The new standard will be formally submitted for approval to bSI in summer 2023.

Property name	Data type
Riser height (in metres)	Number
Tread depth (in metres)	Number
Handrail size (width of handrail)	Number
Horizontal length (in metres)	Number
Width (in metres)	Number
Staircase name	Text
Max capacity	Number

Figure 1: An example of some common data properties for stairs supported in multiple pedestrian modelling tools

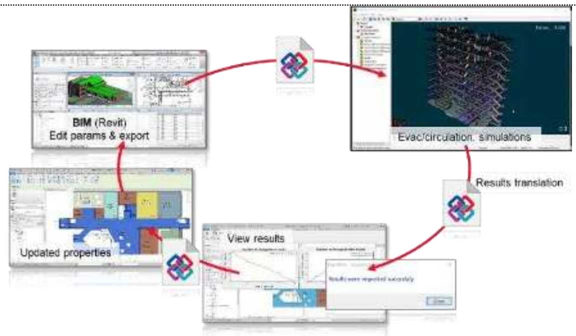

Figure 2: A sample workflow for the IFC data at work

To support this work, a prototype open-source add-in for Revit has also been developed to demonstrate the integration of this new approach [2], as shown in Fig. 2. When approved, this standard will support a new data pipeline from BIM to simulation platform. Data loss can be minimised, reducing the friction in multiple design iterations and reassessment. BIM will act as the hub for the "golden thread" of building & performance data, supporting research, practitioner design iterations and regulatory review.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Motion propagation in response to an external impulse

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In high-density crowds, a local motion at microscopic scale can propagate through the entire crowd. The fact that this microscopic motion increases the density locally can lead to macroscopic phenomena for example 'density waves' [1]. These density waves are caused by motion propagation within a crowd, which only occurs when individuals interact and impulses are transferred. How an external impulse is passed on exactly and which effects this has on individuals is still not fully understood.

To further investigate this, experiments focussing on the propagation of a push were conducted within the EU-funded project CrowdDNA [2]. In the experiments, a simplified crowd was represented by five or twenty people lined up in a row. The last person in the row was pushed forward in a controlled manner with a punching bag. The intensity of the push, the initial distance between participants and the initial arm posture were varied. Collected data included videos from the side, head trajectories, 3D motion capturing (MoCap) as well as pressure measured at the punching bag. With a hybrid tracking algorithm [3], the head trajectories are combined with the MoCap data to ensure an analysis of the motion of each limb in relation to other persons.

Figure 1: Exemplary snapshots of two experimental trials. (a) Sideview: With an elbow distance, five participants lined-up in a queue holding their arms up. (b) Top-view: With no distance, 20 participants are standing in a row with their arms hanging down. Head trajectories for the first six seconds are shown as green lines.

The observed individual behaviour as response to the push can be divided into three phases. These are (i) receiving an impulse and losing balance, (ii) receiving and passing on an impulse, and (iii) passing on an impulse and regaining balance. Dependent on the use of hands, we will investigate how the push propagates through the row and whether an impulse is intensified or reduced by the individual behaviour. To identify when a push is passed on, the change of the smallest distance between body to body over time will be compared with the distance of how far hands are placed away from their own body. The projection of the center of mass in relation to the position of the feet is a measure of a person's balance. Furthermore, the linear as well as the angular momentum of the participants will be considered to estimate external forces. Our results could contribute to the development and validation of a pedestrian model for motion propagation in dense crowds where contacts occur.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Optimized path-finding with idiosyncratic movement using Social Force Maps

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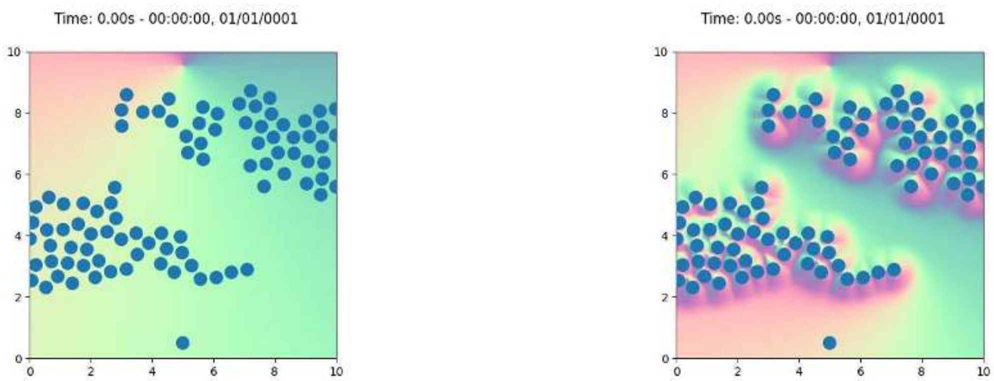
In most modern crowd flow simulations, agent movement is usually modelled to recreate idiosyncracies in movement (social force models), allowing for personal attributes such as a feeling of personal space, or they are modelled logically (velocity based models), allowing for greater coordination and planning between agents. The objective of this paper is to introduce an in-between solution, that allows planning with idiosyncratic variables. The result of this paper is a model that utilizes techniques from regular crowd flow modelling, physics to customize regular pathfinding. The model develops a field of social forces, through which it determines the most "comfortable" path that will eventually reach its target and uses that map to determine direction. This direction is then used as input to an ordinary social force model to move the agent. The difference in pathing can be seen in Fig. 1.



(a) Ordinary SFM pathing

(b) Pathing using social force maps

Figure 1: A comparison of "desired velocities" between old/new models.

In continuously defined simulation models, we talk about two archetypes of models. Force-based models, stemming from the social-force based model [1] and velocity-based models, many of which are variations of the RVO model [2]. Each of the different modelling types has its own strengths and weaknesses, with the force based models suitable for erroneous, natural movement while the velocity based models provide more optimal moment-to-moment movement.

The model we propose in this paper is a model that combines the predictive behavior of the velocity-based models, while allowing for the idiosyncratic, erroneous movement of force-based models. This is done by generating a "social force map" which maps the potential energy required to reach a destination from other positions in an area using social forces.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Experimental study of stepping strategies in dense crowds.

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Dense crowds are challenging environments in which pedestrians may experience contacts and external perturbations. Falling in this context, is one of the life-threatening risks growing as density is rising. To prevent such situations, one must be able to maintain balance after an external perturbation using different strategies like leaning on others or stepping [1]. Until now, to our knowledge, experimental paradigms involving push recovery tasks considered only a single participant [1]. Despite very insightful results, it is hard to generalize such results to a dense crowd since recovery strategies may also depend on neighbors' relative position in these situations. One-dimensional models for learning strategies were developed to study stability in dense crowds but do not focus extensively on stepping strategies. As stepping strategies are key elements to understand risks of falling in dense crowds, models needs to be developed to create accurate dense crowd simulations for safety. Current dense crowd simulations [2] may take into account contacts but do not grasp the complex underlying stepping strategies allowing people to maintain balance in these circumstances. The absence of models for such phenomenon is likely linked to a practical lack of detailed data sets regarding stepping strategies in dense crowds. The release of precise solutions based on inertial measurement units (IMU) for motion capturing recently opened up new possibilities to study these previously "invisible motions" and explore stability in the challenging context of dense crowds. Our objective was to investigate step triggering and step characteristics of people within dense crowds in reaction to external perturbations. In particular, we would like to monitor the changes in the stepping behavior of the participants as crowd density grows. Interests are also given to the effect of hand contacts on step characteristics and step triggering is also investigated. We propose to explore stepping strategies through whole body characteristics such as center of mass position and velocity relative to paticipants' base of support. To reach this objective, experiments were conducted (in the frame of CrowdDNA project) involving 20 young adults, all wearing motion capturing (MoCap) suits (Xsens - MVN Link). Participants were asked to stand in a given configuration (rows, small groups). Then, their motions were recorded as they received an external perturbation from an experimenter. An external perturbation was applied using a punching bag hanging horizontally maintained at participants' shoulders level, see Fig. 1. The global participants' motion was also recorded using a camera fixed to the ceiling of the experimental venue. Relative head trajectories of participants were then extracted set in the same referential using the software *PeTrack* [3, 4]. Participants' center of mass trajectory was computed using the *CusToM* library [5].

Figure 1: Participants set in a *Three rows* configuration about to receive an external perturbation.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Stochastic fluctuations of pedestrian dynamics along curved paths

Geert van der Vleuten[1], Federico Toschi[1], Wil Schilders[1], and Alessandro Corbetta[1]

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As we walk towards our destinations, our trajectories are constantly influenced by the presence of obstacles and infrastructural elements. As a result, the preferred paths toward our destinations often follow (plane) curves, even in absence of crowding.

By means of extensive and highly accurate real-life measurements (7 experiments) we analyse the connection between the stochastic fluctuations inherent to the dynamics and the local curvature of the desired path. At each experiment, stochastic fluctuations are analysed in reference to an average ("preferred") path (illustrated in Fig. 1a).

We find that the average longitudinal walking velocity decreases for increasing preferred path curvature, presented by the fundamental diagram in Fig. 1b. Beside the curvature-dependent averages, we find that the longitudinal and transversal velocity fluctuations are Gaussian-distributed with curvature-independent variances.

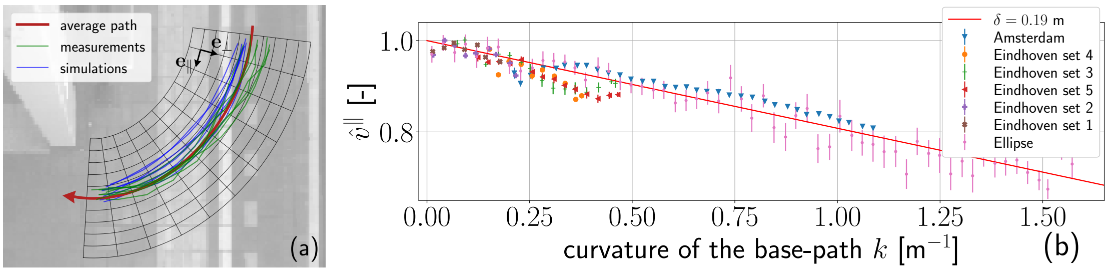

Figure 1: (a): Top view of several measured and simulated trajectories in Amsterdam train station. Indicated are the average path and coordinate frame with longitudinal, $\mathbf{e}_{\parallel}$, and transversal directions, $\mathbf{e}_{\perp}$. (b): fundamental diagram of the average longitudinal velocity versus the curvature of the desired path. The longitudinal velocity in this plot is scaled such that $\hat{v}^{\parallel}(k = 0) = 1$. A linear fit ($\hat{v}^{\parallel} = 1 - \delta k$ with $\delta = 0.19$) is plotted in red.

We show that the walking dynamics along curved paths can be modelled quantitatively by extending the Langevin-like model in Ref. [1], in which the individual acceleration of pedestrians is determined by a superposition of social forces. The desired curved paths are included via the differential-geometric notion of affine connection, which enables a seamless generalisation without requiring coordinate changes of the force terms.

We calibrate the model using the measured trajectories in Amsterdam train station (Fig. 1a). The probability density functions of relevant observables (longitudinal velocity, transversal velocity, and lateral deviation) obtained with simulations are compared with the empiric distributions in Fig. 2. We observe that the stochastic properties of velocity and position fluctuations are captured by the model.

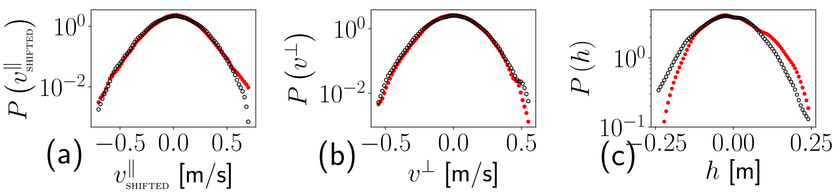

Figure 2: Comparison between empiric (red dots) distribution functions with the from simulations obtained distributions (open dots) of the curvature-corrected longitudinal velocity (a), transversal velocity (b) and lateral deviation (c).

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Falls, Balls and Evacuating Halls: Applications of Biomechanical Analyses of Human Movement

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University College Dublin, Ireland

Models of crowd flow typically assume uniform behaviour and movement patterns for all pedestrians, regardless of physical abilities, age and motivation. However, with increasing trends in urbanisation, obesity and an ageing demographic, assumptions made in current models may not be fit-for-purpose. In 2020, around 75% of the population in the EU-27 lived in urban areas, with the proportion of people aged 65 and older across the EU increasing from 21.1% in 2022 to a projected 29.5% by 2050 (Eurostat). The European Disability Forum estimates that around 100 million people in Europe have a disability, and as of 2019 approximately 35% of adults aged 18+ years were classified as pre-obese (European Health Interview Study, Eurostat). There are obvious impacts of these trends on pedestrian mobility and evacuation strategies due to physical decline and altered gait patterns, walking aids, sensory/cognitive impairments, limited energy capacity, interperson dynamics and cultural differences. If these factors are accounted for in models of crowd flow, it is generally done by modifying gait speed or space between people, often using arbitrary mathematical adjustments because suitable empirical data is scarce and difficult to capture in real-world scenarios. However, it may be said that oversimplification of the movement of crowds in today's world is a precarious position to take.

This talk seeks to leverage insights from the biomechanical analysis of movement in the field of sport and health that can go some way towards a better understanding of the impacts of the trends outlined above on crowd flow and evacuation dynamics. We will go on a journey through the author's research in these fields, demonstrating how wearable sensors placed on the legs during walking have been used to predict falls risk in older adults and people with Parkinson's; how spatial analysis in rugby has been used to understand game tactics and decision-making, and how biomechanical/physiological analyses of gait have been applied to understand stop/start processes when walking in a group, using high resolution optical motion capture. We will explore the overlap between pedestrian evacuation dynamics and the biomechanical analysis of movement with respect to people interactions and what each discipline can learn from the other.

While the field of pedestrian evacuation dynamics has long been engaged in modelling interactions between people, the dynamic and evolving nature of pedestrian movement in a crowd and interactions with other pedestrians is not well understood at a micro level. Figure 1 shows the types of "micro" parameters we have explored in laboratory experiments that will be discussed in this talk. Treating individuals as identical 2D rigid bodies overlooks the variability in walking behaviours and thus may not accurately simulate realistic crowds. The phenomenon of intra-person and inter-person movement variability will be examined in this talk, as much of the author's research has focused on this topic. Movement variability is a phenomenon that has only relatively recently been recognised as an important issue in the field of movement analysis in sport and health. While previously movement variability was seen as error that should be ignored, it is now recognised that movement variability is an inherent feature of a healthy, adaptive motor control system. There is now a body of evidence demonstrating the association of gait variability with health, and changes within this variability with age or disease. A study by the author demonstrated that postural sway in healthy older adults measured in their home at the same time every day over the course of 8 weeks showed variations of up to 40cm in sway length across the study period, *within the same person*

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(Figure 2). Thus, the question of how movement variability may be included in crowd flow models is a timely consideration.

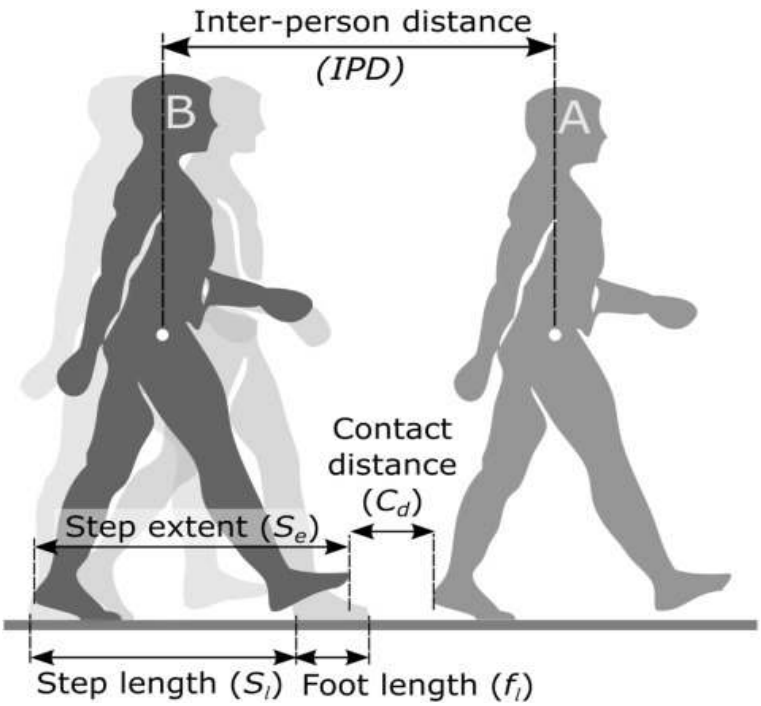

Figure 1: Examples of movement/gait parameters that can be used in models of crowd flow models. These parameters have also been shown to vary in different cohorts of people (e.g. aged versus young). [Diagram provided by Dr. Pete Thompson}

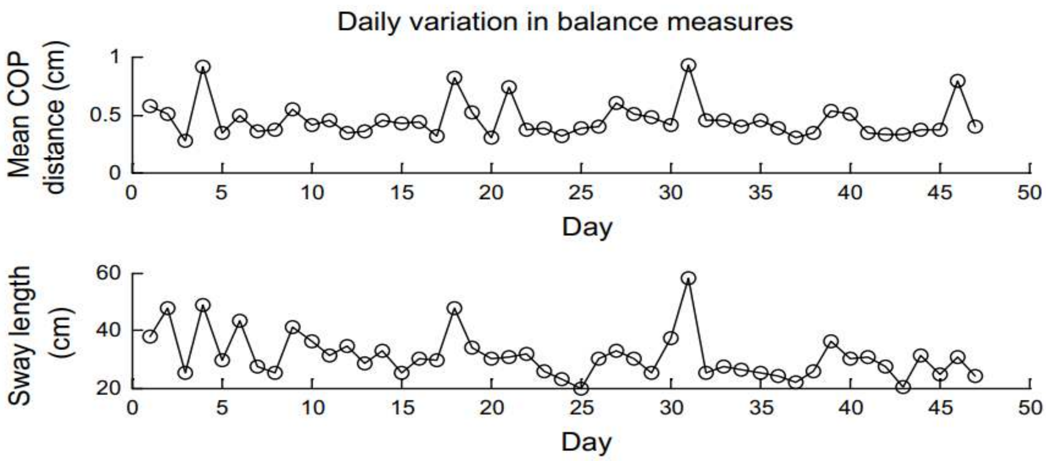

Figure 2: Postural sway data for one individual taken daily over an 8-week period. This data highlights the phenomenon of day-to-day movement variability as a significant feature of healthy human movement.

The audience will be invited to consider the value of including nuanced movement parameters in crowd movement modelling, how these parameters can (and cannot) be captured with current measurement technologies and what opportunities lie ahead. The imperative of interdisciplinary collaboration in inclusive design will be discussed and a research roadmap for future directions in this space will also be presented for interactive discussion with the audience.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Heterogeneity of Agents in Cellular Evacuation Model Explains the Decreasing Bottleneck Flow

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Heterogeneous crowd consisting of pedestrians with essentially diverse abilities (velocity, acceleration) behaves in certain aspects differently than a homogeneous crowd consisting of "average" pedestrians. This study investigates the influence of heterogeneity in less obvious aspects connected to the ability to navigate through a crowd in front of a bottleneck. Simulations of cellular multi-agent model suggest that the heterogeneity in ability to push through the crowd (represented by aggressiveness γ) and willingness to bypass the crowd (represented by sensitivity to occupation k_O) may be responsible for the bottleneck flow decreasing in time – a phenomenon observed in experiments [1].

We consider a floor-field based cellular model introduced in [2] with improved mechanism of target-cell choice $P(y \leftarrow x)$, defined as probabilistic mixture of two strategies

$$P(y \leftarrow x) = (1 - k_O)P_S(y \leftarrow x) + k_O P_O(y \leftarrow x)\,,$$

where $P_S(y \leftarrow x)$ neglects the occupation of neighbouring cell (agent follows its predecessor by means of bonds principle) and $P_O(y \leftarrow x)$ strictly excludes the choice of an occupied cell (agent tries to bypass the crowd). Conflicts are solved according to aggressiveness parameter γ (the higher the aggressiveness, the higher the probability to win the conflict). Presented results are based on the series of Monte-Carlo simulations aggregated in sample averages over 1000 trajectories per parameter setup.

The time evolution of the bottleneck flow J_t was analyzed by means of Muggeo iterative algorithm for piece-wise linear model-fitting. In case of homogeneous set of agents it was possible to find a stationary flow time interval, such that $J_t \approx J_{\text{stac}}$. However, in case of heterogeneous set involving two groups of agents with different aggressiveness parameters $\gamma_1 < \gamma_2$, the flow J_t exhibited a linearly decreasing trend, with minimum and maximum values corresponding to stationary flow for γ_1 and γ_2 respectively, as depicted in left graph in Fig. 1. The heterogeneity in sensitivity to occupation k_O had similar effect on bottleneck flow, but the slope of the flow decrease was not so steep. Dominating effect of such heterogeneity consists in different path choice in front of the bottleneck, see right part of Fig. 1. As expected, agents with high k_O were trying to bypass the crowd from left or right, while agents with low k_O preferred the shortest path using the motion in line.

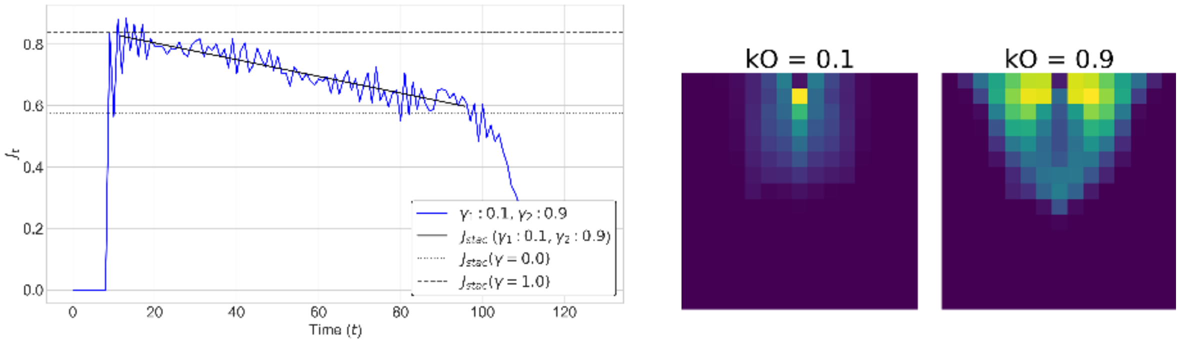

Figure 1: Left: Time evolution of sample average flow J_t for two groups with different γ. Right: Density of agent trajectories passing through given cell with respect to different k_O in heterogeneous simulation.

A conclusion can be drawn that the heterogeneity in agent properties related to ability and strategy to navigate through the crowd can explain important observed phenomena of bottleneck flow.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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A psychological entity, a gathering of small groups, a herd of bodies? How to approach an anonymous crowd – a socio-psychological perspective

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"The Crowd: A Study of the Popular Mind" written by Gustave Le Bon [1] is still very present in academic discussion about crowds. Le Bon assumes that the crowd is an entity and processes of transmission like contagion should be examined to understand the underlying social mechanisms. Although social categorization theory offers an alternative explanation of social dynamics in crowds, namely shared social identity, phenomena that are not based on strong social bonds are still not covered by this approach. Everyday crowd experiences like waiting on the railway station platform for the train or just gathering in hotspots like in front of an Apple store which is launching a product are still a blind spot for crowd research. These situations are social, but also anonymous.

In this talk I would like to present some of my social psychological and sociological conceptualizations of crowds as anonymous sociality. In my work I rely on the micro-sociological observations of Erving Goffman [2], on the conception of everyday life of Alfred Schütz [3] and on the phenomenology of perception and sociality [4,5].

Based on theoretical considerations, an interview study, and an experiment, I intend to show that beside shared social identity several other dimensions of sharing have to be considered when dealing with crowds. The main points are:

1. Anonymity should be considered as a common ground of (shared) understanding of situations in public (not intimate) space with social regulations of behaviour regarding social distancing or restricting forms of communication, and not as an individualised and/or asocial from of gathering.
2. Being in a crowd is an embodied experience which cannot be disconnected from the subjective bodily perception. Shared bodily experience is not the result of shared social identity, but it is a basic experience in crowds.
3. Everyday situations are based on common expectations regarding the procedure of the social dynamics which frame the behaviour of the individual actors.
4. Deviation from expectations causes the breaking of the unwritten rule of anonymity and generates a social re-setting of the situation in which the common ground needs to be restored.
5. Collective affective states are permanent features of crowds, not just exceptional phenomena in emergencies.

Based on the findings, I aim to summarise in which sense und context we can speak of the crowd as an entity and what kind of implications can be derived from this view for interdisciplinary crowd research.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Deterministic Simulation of Pathogen Transmission via High Fidelity CCM/CFD

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Advances in computational fluid [2] and crowd [1] dynamics (CFD, CCD), as well as computer hardware and software, have enabled fast and reliable simulations in both disciplines. A natural next step is the coupling of both disciplines. This would be of high importance for evacuation studies where fire, smoke, visibility and inhalation of toxic materials influence the motion of people, and where a large crowd can block or influence the flow in turn. The same capability could also be used to simulate with high fidelity the transmission of pathogens in the presence of moving pedestrians, enabling a much needed extension of current simulation technologies [2]. The present work considers a tight, bi-directional coupling, whereby the flow (and any pathogens in it) and the motion of the crowd are computed concurrently and with mutual influences. This implies that the exhalation and inhalation of pathogens is taken into acccout. Enabling technologies that made this tight coupling feasible include: a) Development of immersed boundary methods; b) Implementation of fast search techniques for information transfer between codes; and c) Strong scaling to tens of thousands of cores for CFD codes.
As an example, we include a long corridor of 80m x 10m x 4m at a train station. The pedestrian flux is of 2p/sec, leading to approximately 250 pedestrians at any given time. Of these, 70% are considered healthy, 10% asymptomatic and 20% infecting via sneezing. No masking is assumed. The CFD mesh had 120M elements with a minimum size of about 10cm. The simulation was run in 3 phases: a) Every code is run independently until 'things settle down'; b) The restart files are taken, and the run continues in fully coupled mode, until 'things settle down'; c) The restart files are taken, and the run continues in fully coupled mode imposing the boundary conditions for sneezing pedestrians.
The run took 8 hours on 1,024 cores for a physical time of two minutes.

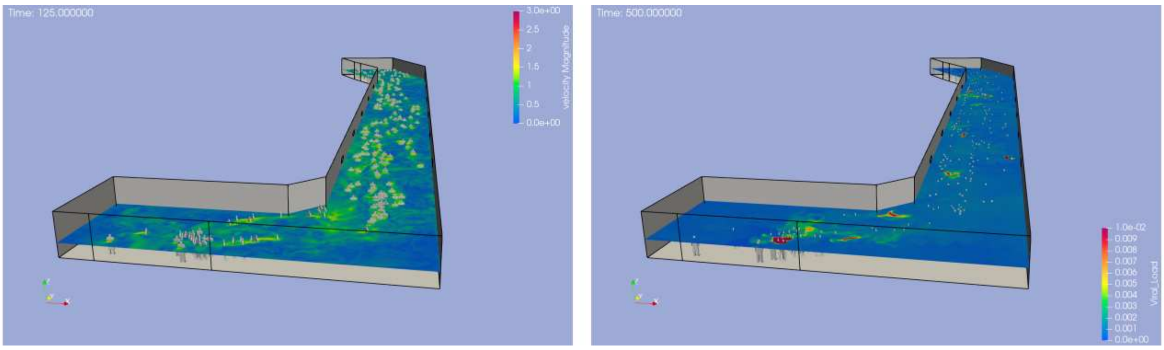

Figure 1: Long Corridor: Left: Velocity at Headheight, Right: Viral Load at Headheight

The final paper will contain more implementation details and examples.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Parameter study to quantify uncertainties in agent-based simulations of airborne pathogen transmission in dynamic crowds

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The coronavirus disease 2019 (COVID-19) pandemic boosted the development of agent-based exposure models. Microscopic crowd models have been equipped with new features, which capture pathogen transmission, for example, as described in [1, 2, 3]. These combined models allow studying the risk of exposure for individuals occupying specific indoor environments. However, particularly the parameter values for airborne transmission of the coronavirus are rife with uncertainty due to scarce experimental data. This delimits the predictive power of simulations. Fig. 1 illustrates how uncertainties in the input may result in misleading output. In this study, we pose the research question of how we can identify influential parameters and quantify their impact on the output of simulations of airborne pathogen transmission in moving crowds.

Figure 1: Uncertainties (characterized by probability density functions, red) in the input propagate through the model and yield an uncertain output. Evaluating only one sample (blue) can return a non-representative result.

Methods for global sensitivity analysis and forward propagation aid us in addressing the question. More precisely, we calculate Sobol' indices [4] and perform Monte Carlo simulations. We apply both techniques to a model for transmission of the coronavirus, which we developed in a previous study [3].

The simulated scenarios represent everyday situations, for example, pedestrians waiting at a supermarket cash desk or an airport gate, or walking through a concourse from one gate to another one. The microscopic crowd model allows us to take into account transmission mitigation strategies that came up with the COVID-19 pandemic and affect the pedestrians' locomotion behavior. For each pedestrian, we observe the degree of exposure, that is, the number of pathogens they inhaled. The sensitivity analysis shows to which extent the impact of parameter uncertainties on the pedestrians' degree of exposure depends on the scenario. It also showcases how the need for and the efficiency of mitigation strategies depends on the situation: The forward propagation unveils a far higher average exposure in waiting scenarios than in the walkway scenario. Our simulations show that, independent of physical distancing, more pedestrians are exposed to airborne pathogens when pedestrians queue in a typical line, than when they remain stationary in a waiting area after receiving a ticket. In contrast, we find that the maximum exposure of a single person is greater in the waiting area than in the queue. Two parameters related to the propagation of airborne pathogens emerge much more influential than, for example, the half-life of pathogens.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Understanding crowd responses to perceived hostile threats: An innovative multidisciplinary approach.

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Crowd responses to emergencies have been investigated by researchers from different disciplines using a variety of methods. In recent years, data-driven approaches to crowd behaviour in evacuations have rapidly evolved [1]. In particular, advances in machine learning have allowed researchers to use real-world data to predict patterns of crowd movement. While this approach is extremely useful to extract general behavioural tendencies, it provides limited insight into *why* people behave in these ways. Extrapolation of findings from normal movement scenarios to emergency scenarios carries limitations. Collective responses to threats include behaviour such as egress, helping, information sharing, alerting emergency services, and more. Thus, accurate models of crowd behaviour must consider the diversity of behaviour and potential changes in people's responses in relation to the context under consideration. Here, we adopt a theory-driven and evidence-based approach to understanding crowd behaviour. We innovatively combine multidisciplinary methods from psychology and evacuation research to provide a comprehensive view of how and why people respond to perceived threats.

Our project includes qualitative and quantitative research methods that together enhance our understanding of crowd evacuation behaviours. First, a systematic review of incidents as identified through news media coverage allows us to pinpoint the broad contextual variables – such as a rise in terrorist attacks -- that influence people's interpretation of whether a particular situation is threatening. Second, we explore why the behaviour occurred from the perspective of the people who experienced the emergencies, with detailed, nuanced accounts from interviews providing insights into what and who they attended to in the emergency. This, combined with CCTV footage analysis of behaviours, gives us a deeper understanding of the circumstances under which behaviours occur in emergencies.

Altogether, archive and interview methods suggest important factors that may impact crowd responses. However, they cannot establish causal relationships underlying behaviour. To gain further knowledge on the causes of behaviour, we conduct experiments to systematically test the specific predictors of behaviour using virtual reality (VR), that has proven useful to investigate human behaviour in evacuations [2]. We combine VR technology, priming methods and self-report measures from social psychology, and established measures from evacuation research. Thus, we carefully manipulated the variables identified in the qualitative studies, to understand their impact on public responses to emergencies. We use these results to build a theoretical model of the processes underlying behaviour. The validity of this model is tested by its ability to account for the behaviours observed in the case studies.

In sum, our triangulated methodological approach provides a framework for combining diverse research methods that collectively build the necessary knowledge to help create more accurate models of crowd behaviours in emergencies.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Beyond stationarity on pedestrian flow fundamental diagrams

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Pedestrian Fundamental Diagrams (PFD) consist of pragmatic representations of pedestrian traffic data, allowing effortless reading of key parameters (e.g., jam density) and straightforward comparisons (e.g., walking behaviour on land vs. water). Such diagrams also reveal performance scattering, data representativeness, and functional patterns (e.g., linearity), among other features. Knowledge of the PFD can be leveraged to design and assess pedestrian facilities either in normal or emergency conditions, as the data is not specific to a given geometry, even though some geometric constraints may apply. From experiments with volunteers or field observation, the general data treatment pipeline rests on: video processing for trajectory extraction; speed calculation, usually with data smoothing to mitigate head swaying; density calculation, usually by means of a rectangular measuring area or a Voronoi diagram; and time series analysis. The later step seeks intervals of speed and density (or flow rate) that are relatively stable, configuring the steady state. Across most of the literature, a manual judgement of stationarity is performed, whereas [1] presents a formal procedure to calibrate and detect steady states from bottleneck experiments. A repeatable stationarity procedure can be considered a good practice, making results reproducible and the data treatment pipeline objective. Inconveniently, pedestrian datasets might be of small sizes and oscillative over time, as shown in Fig. 1(a) [2]. Consequently, important information is lost due to the stationarity paradigm. Notwithstanding, the pedestrian traffic literature misses a deeper assessment of the nature of the steady state dynamics, generally relying on an empiric notion of scatter minimization to justify the data treatment pipeline. Fig. 1(b) [3] reveals an approach to a steady state characterized by a declining speed, possibly because this interval mitigates speed change. Our research proposes a novel approach to the pedestrian time series analysis, introducing an easy-to-deploy concept of speed-density correlation filter by which a given interval is accepted if a threshold speed-density correlation is reached. The time series is sliced into intervals of length Δt and the Spearman's correlation index is calculated for every slice t and compared to a critical value ($r_{Spr}(t)<r_{Critic}$). The Voronoi method is used to determine density inside a measuring area of dimensions $L_x \, x \, L_y$. From experiments conducted at the Jülich Research Centre in unidirectional corridors, the parameters Δt, r_{Critic}, L_x, and L_y are varied to investigate the corresponding speed-density PFDs. The comparison of the resulting PFDs has shown that the proposed correlation rule outperforms the manually selected intervals, not only because it minimizes scattering, but also because it increases the range of density and speed. Fig. 1(c) compares the PFDs obtained from the proposed method with the manual steady state procedure.

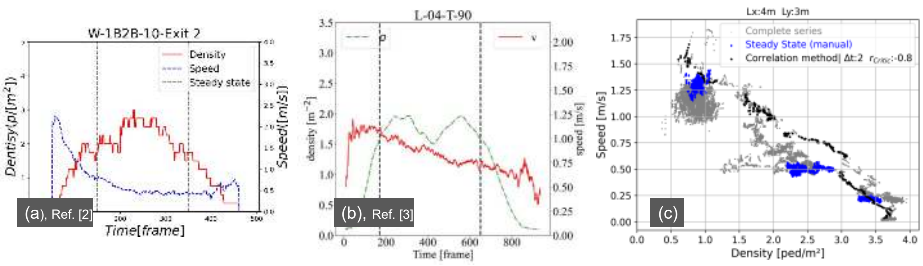

Figure 1: Effects of stationarity on pedestrian fundamental diagrams.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Scaling Analysis of Crowd Dynamics

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In fluid mechanics, the dimensionless Reynolds number allows to identify and predict patterns in different flow regimes. In pedestrian dynamics, the analogue of the Navier-Stokes equation is not known. However, there is a rich variety of empirical data and an ever-increasing zoo of different models. In an original endeavour to introduce and exploit dimensionless numbers, we have managed to delineate qualitatively and quantitatively different flow regimes on the basis of empirical data. We introduce the Intrusion number $\mathcal{I}n$ and Avoidance number $\mathcal{A}v$ which will allow a quantitative distinction of different flow regimes. $\mathcal{I}n$ is based on spatial distances and quantifies the intrusion of the personal space. $\mathcal{A}v$ is based on the time-to-collision and quantifies the urgency of an expected collision. In the 'phase' diagram in Fig. 1, different regimes can clearly be distinguished. These regimes are qualitatively indicated by the colored gradients. For example, low-density single-file motion (represented by ▲) is located in the bottom left corner ($\mathcal{I}n, \mathcal{A}v \ll 1$). This corresponds to free-flow of non-interacting pedestrians walking at their desired speed. The single-file data-point with the highest $\mathcal{I}n$-value corresponds to a strongly congested regime with stop-and-go waves. In bi-directional flow, the more subtle difference between the dynamics during (▼) and after ($\star$) the formation of lanes is captured correctly, in particular by a higher avoidance number in the former. Rescaling pedestrian models by identifying the underlying dimensionless variables shows that these often involve dimensionless numbers similar to $\mathcal{I}n$ or $\mathcal{A}v$. Conversely, new models based on $\mathcal{I}n$ and $\mathcal{A}v$ can be reverse-engineered. Comparing experimental results with simulations in limit regimes shows that the 0^{th}-order of pedestrian behavior is correctly described if and only if the governing dimensionless number is included in the model. In particular, time-to-collision-based models can not describe flows in uni-directional corridors or static crowds while distance-based models can not solve conflicts in the low-density cross-flow adequately. The findings confirm but constrain the results of [1] empirically and theoretically: the time-to-collision is a more suitable descriptor than the spatial distances only in a specific regime while the opposite is true in other regimes. In contrast to the Reynolds number, where a macroscopic length scale allows the prediction of flow regimes and corresponding approximations even in unknown scenarios, the calculation of $\mathcal{I}n$ and $\mathcal{A}v$ is based on microscopic information, i.e. the trajectories. The possibility to use a simple model to predict $\mathcal{I}n$ and $\mathcal{A}v$ is discussed.

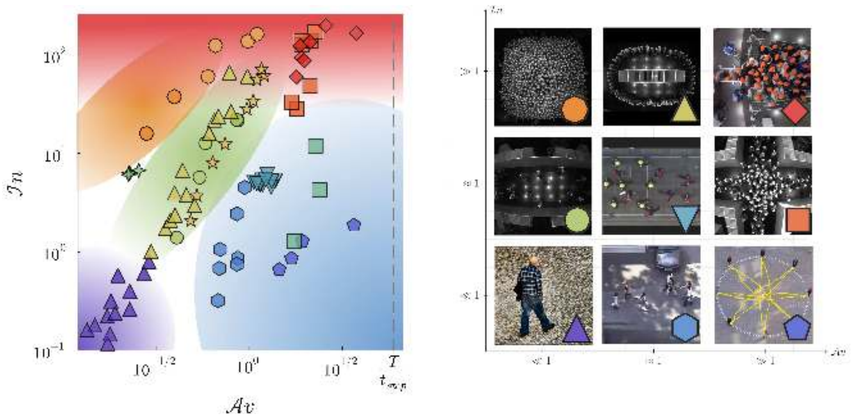

Figure 1: Intrusion number $\mathcal{I}n$ and Avoidance number $\mathcal{A}v$ calculated from a broad collection of pedestrian data sets (*left*) and exemplaric snapshots of the experimental or observational set-ups (*right*). Each point corresponds to an experimental run or observational sequence. In most set-ups the global density is varied between the runs. The colored gradients are a visual guide, to indicate different regimes.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Stress Level of Pedestrians in the Presence of Autonomous Vehicles

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Virtual reality (VR) has become a powerful research tool in various disciplines, including transportation engineering. Having VR experiments in the controlled laboratory setting has enabled application of physiological sensors. Electrodermal activity (EDA) sensors have been used to identify stressful walking [1] and cycling [2] manoeuvres in VR. This study investigates the stress level of pedestrians when encountering autonomous vehicles (AVs), by developing an experiment in VR. The two-way Front Street near Union Station in Toronto was modelled in VR. In each session, participants were located on the sidewalk and they were asked to cross the street when they felt comfortable within 60 seconds. Shimmer3 GSR+ sensor was used to measure their stress level when crossing the street.

Different variables were considered when designing the experiment: AV penetration rate: traffic flow, other pedestrian behaviour (controlled by computer), AV signal, street median, time of day, and weather. These factors were prioritized based on research aims to create each session. There were 12 sessions designed for each participant and they were repeated to explore learning and habituation effects. There was a 5-minute break in between the two rounds.

Figure 1 shows the EDA signal of a participant throughout the whole experiment. Less peaks and fluctuations are observed during the initial phase of the experiment, when participants were asked to read a short story to identify their baseline EDA. Immediately after running Session 1, a sharp peak is observed which indicates an arousal due to the excitement of being immersed in a new VR environment. A relatively smaller peak is present in almost every session which is associated with the crossing moment. The size of these peaks indicates the stress level and demonstrate people's reaction to AVs versus normal cars. This study with more than 50 participants shows promising results in determining the stress level of pedestrians in the presence of AVs and demonstrates the capabilities of VR and EDA sensors for future research.

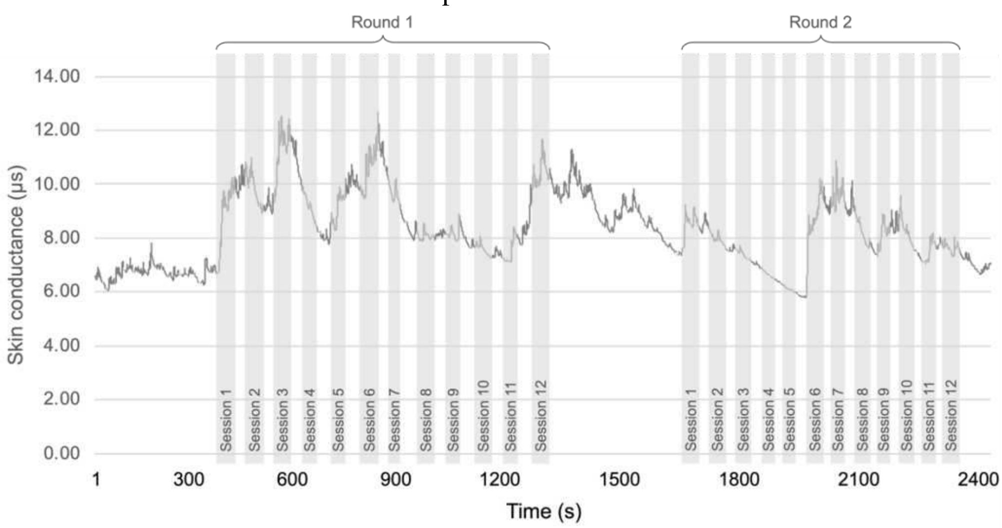

Figure 1. Sample electrodermal activity of one of the participants

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Trends in reporting crowd accidents over the last 120 years

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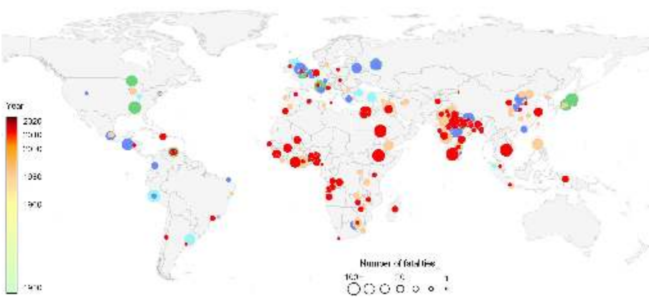
Every time a large crowd accident occurs, public and researchers' attention is set on the subject. Previous accidents are brought back to memory and what is normally a rare occurrence appears as a terrible reality. However, as time goes by, memory vanishes and minor accidents get unnoticed although they still typically occur almost once a month. In such a context it is difficult to obtain a detailed overview on crowd accidents and identify possible trends. For instance, a simple yet non-trivial question playing an important role to motivate research on crowd behavior is: are crowd accidents on the rise? Similarly, it is also important to understand which kind of accident is increasing and which countries need to employ more resources to tackle this problem.

In this work, we present the results from an analysis of press reports on crowd accidents collected for the period 1900–2019. After confirming on the validity of each report and determining whether each accident fulfill our definition of "crowd accident", we extract important information such as the number of fatalities and people injured and the reported crowd size. The text used in the report is also extracted. Our analysis focus on two distinct aspects: the reported values and the words used in describing each accident.

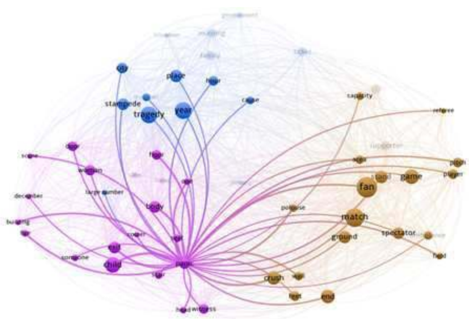
Numbers are used to analyze the evolution in the total number of accidents per decade, showing an exponential rise over the last 120 years. In that regard, we also provide initial evidence to show that the rise is only partially related to a real increase, with reporting bias also likely to play an important role. But numbers clearly show that accidents in religious events are on the rise and countries belonging to the lower-middle income group are increasingly the theater of crowd disasters (see Fig. 1a).

The lexical analysis on the reports' text is based on the frequency of co-occurrence of specific words and density maps. The outcome (with an example provided in Fig. 1b) allows us to understand which words are more commonly used in association with other words and whether they are used within a similar context or not. On the purpose of this analysis, 372 press reports were selected from a total of 834 and are representative of 26 reporting agencies. In addition, 68 Wikipedia pages on crowd accidents are also analyzed. Both type of sources are compared with scientific publications to check possible differences in the use of language.

The numerical analysis has been already concluded and its main results will be presented at the conference. The lexical analysis is still underway, but data has been already collected and organized. In addition, analytical tools have been already tested, so we are confident at least preliminary results on the lexical analysis will be ready to be presented at PED2023.



(a) World map of crowd accidents



(b) Word use in press reports

Figure 1: Results from the analysis of press reports on crowd accidents from 1900 to 2019. A large number of accidents occurred over the last 20 years with India and West Africa being particularly affected. The use of words tend to relate to the context of each accident, with tragedies occurring during soccer matches showing common features.

Timetable (p. 11)

ToC

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Reconstruction of the Loveparade disaster from the perspective of visitors. Analysis of witness statements

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In the Loveparade disaster in 2010 a very dense crowd situation appeared in which 21 visitors of the dance festival were killed, and several hundred injured. This paper presents an analysis of a random selection of 136 witness statements of visitors who had been within this life-threatening crowd. It combines perspectives from psychology and physics.

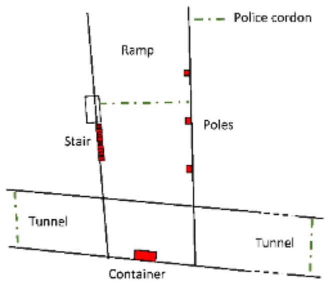

Figure 1: Representation of the location and landmarks in the environment of the deadly crowd

In addition to analyses of the complex, multifactorial overall situation that led to the disaster [1] or of the dynamics of the crowd from above on the basis of CCTV footage [2] this study approaches the dynamics from within, from the perspective of visitors. They had been interviewed by police officers in the hours, day, or weeks after the disaster. This material can now be analyzed scientifically after the judicial process ended in 2020 without a verdict. Eyewitnesses describe how they perceived the situation, how they (and others) behaved and what they experienced. Furthermore, they can provide information about what collective dynamics there were in the crowd and how they affected their bodies.

Psychologically, the situation is characterized on the one hand by a strongly limited perception (only the backs of the direct neighbors are seen, free areas in the back are not noticed, the danger of the situation is noticed only late) and on the other hand by a very good perceptibility of the possibilities to climb out of the crowd caught on the ramp via the stairs or the poles. This has led to a strong pressure in the direction of the stairs and poles. At the same time, visitors most often describe that they helped each other. Even though fear of death is reported, the witnesses contradict the idea that there was a mass panic. As the most dangerous dynamics a combination of falls (often after people had fainted) and transversal waves could be reconstructed. Falling people can create a hole in a tightly packed crowd. Due to the pressure people at the edge of the hole are pulled in, creating a pile of wedged bodies. These results are in conformance to reconstructions of other disasters (i.e. [3]). In comparison to the case analyzed in [3] the situation at the Loveparade is more complex. In addition, the study presented here relies on a larger amount of data, and a more systematic content analysis of physical and psychological aspects. This methodology allows to describe the dangerous dynamics in a high level of detail.

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Multi-Agent modelling of Dense cRowd dynAmicS (MADRAS): Application to the Festival of Lights (Lyon)

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Trustworthy models for the dynamics of dense crowds are crucial for the prediction of pedestrian flow and the management of large crowds. However, current models suffer from some severe deficiencies, especially at high density. In this context, the MADRAS project aims to develop innovative agent-based models to predict and understand dense crowd dynamics (from 2 to 8 ped/m2) and to apply these models in a large-scale case study. Three complementary modelling approaches are being pursued: (i) neural networks (NN) that will be trained on available data to predict pedestrian motion as a function of their local environment and trajectory [1], (ii) a physics-based model coupling a decisional layer, where a desired velocity is selected according to an empirically validated collision-anticipation strategy, and a mechanical layer, which takes care of collisions and contacts, (iii) an agent-based model providing a versatile behavior allowing agents to switch dynamically between a library of models on operational, tactical and strategical levels depending on the density.

These approaches will be confronted with novel validation methods, using data from controlled experiments. The models will then be exploited at larger scale to simulate the flows on crowded streets at a real mass gathering, the Festival of Lights in Lyon. To this end, empirical data have been collected during the Festival of Lights 2022 (cf. Fig. 1): it combines filming some streets and squares from above, gathering GPS tracks and contacts data while crossing the square.

The objective of this contribution is twofold. First it will present the dataset gathered during the Festival of Lights 2022 and cleaned using a combination of various approaches. Second, it will introduce the overall approach developed in the MADRAS project allowing modelers to combine data-driven, physical-based and agent-based models in order to simulate this evacuation phenomenon, at different scales.

Figure 1: Place de Terreaux at the Festival of Lights in 2022

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Relationship between Pushing Behavior and Crowd Dynamics

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Crowds often form due to limited capacities of walking facilities, causing people to gather in close proximity. Without any clear guidance for queueing, crowds are susceptible to pushing behavior by pedestrians who want to quickly access their goal. It is especially common in scenarios where there is only one main exit or entrance, such as for entrance systems for events. When people push their way through a crowd, it can create a dense environment [1, 2] that can be hazardous to the person being pushed. However, pushing behavior in crowds is not always present and can vary depending on social context and norms [2]. It may decrease or disappear if the environment promotes unity and helping others [3], but can also increase or appear as motivations shift. Pushing behavior is therefore dynamic and can change over time.

Lügering et al. [4] developed a forward motion category system that includes the following categories of pushing: strong pushing, mild pushing, just walking, and falling behind. This system allows researchers to rate individual pushing behavior which can be combined with pedestrian trajectories, allowing the individual effects to be seen throughout the sequence. The proposed work aims to use this rating system and to examine the relationship between pushing behavior and the physical properties of a crowd. To do this, we will observe pushing occurrences from laboratory studies using trajectory data extended by pushing states and link them with properties such as distance to the goal, density and flow (see Fig. 1). This will allow us to identify individual pushing occurrences on a large scale and collective patterns, and to understand the causal relationship between pushing behavior and changes in the crowd. This understanding can later be used to inform the design of crowd management strategies and improve safety in crowded environments.

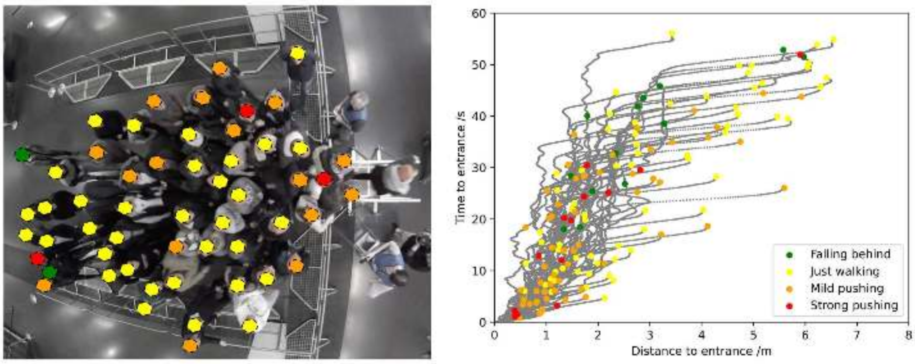

Figure 1: Snapshot of the experiments on the left with marked pushing behavior of the participants as in the legend on the right. We plan to analyze and compare data for different corridor widths. A first result of the time-distance relation and pushing behavior is shown on the right.

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Evacuation models for rapid multi-hazard tabletop exercise deployment

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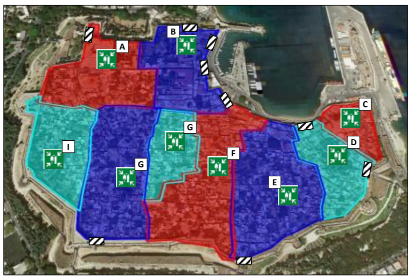
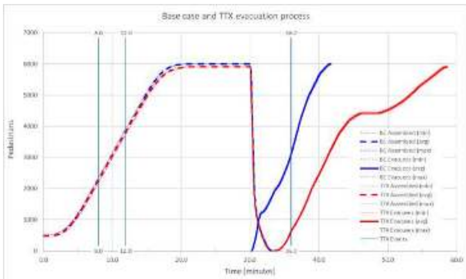
To prepare for large scale emergencies, authorities and emergency commanders utilise several types of trainings ranging from seminars to full-scale exercises. Within this continuum of exercise types, tabletop exercises (TTX) are habitually used to familiarise participants with mitigation strategies, population management and evacuation procedures. Commonly, TTXs are paper-based, and if computerised, utilise basic electronic maps, and tend to be scripted and non-dynamic. Information flow is unidirectional as the script dictates how the exercise unfolds. These exercises, have little capacity for producing feedback to the participants related to the impact that the received scenario injects, the decisions taken, and that the hazards have on the evacuation process. Here an evacuation simulation model [1,2,3] is proposed to augment the TTX experience at real-time, offering feedback and insights on the impact that such injects, decisions and hazards have on the simulated community. It is anticipated that this information improves training, the response to the TTX scenario, the overall understanding of the complexities related to the TTX scenario and the management of the incident.

To demonstrate the applicability of the proposed solution a case study of a TTX, co-organized by the Rhodes Municipality (RM) and the National and Kapodistrian University of Athens (NKUA) is presented. The urbanEXODUS evacuation simulation software, produced by the Fire Safety Engineering Group (FSEG) of the University of Greenwich (UOG) is used to develop the evacuation scenarios for the Medieval City of Rhodes (MCR). Given its location, the MCR, is potentially vulnerable to a variety of hazards including earthquakes and tsunamis. Mitigating these risks requires preparedness in evacuation strategies and procedures that allows for the efficient and safe movement of people to safety. The proposed solution provides insights and feedback from the rapidly deployed TTX evacuation simulation. The simulation determines the impact that building collapses (due to an earthquake), blocked escape paths (due to debris), procedural adaptations (due to fear of tsunami) and the presence of fire at one of the escape gates, have on evacuation movement, and performance. Without the use of evacuation simulation tools, it is practically impossible for crisis managers to obtain this information or to comprehend the combined effect produced by the urban layout, the population distribution, the evacuation procedures, and the impact of hazards.



(a)



(b)

Figure 1: (a) Each highlighted area within the Medieval City of Rhodes (MCR) is assigned its own assembly location, (b) Evacuation performance (number of evacuees vs time) for the base case (blue), and TTX case (red).

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Revisiting the paper "Simulating dynamical features of escape panic": What have we learnt since then?

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It has been more than two decades since one of the most influential papers of crowd dynamics authored by Helbing, Farkas and Vicsek was published in Nature [1]. Since then, there have been nearly 3,000 and 6,000 citations recorded to this paper respectively by the Web of Science and Google Scholar. The paper is, by far, the most influential paper of the field in terms of the citation metric, but experts also attest that this publication has exerted a great deal of influence, beyond pure referencing, on the general course of crowd dynamics research from the time of its appearance. In a way, it is rather hard to imagine how the field of "crowd dynamics"—like we know it under this title and as a standalone field—would have shaped out had this paper not appeared in Nature at the time.

More than two decades since this publication, it may be time to dissect the extent and also nature of this influence and determine whether this influence has been mostly for the good or for the bad or mixed. And if it had a mixed influence, then what aspects had a positive and what aspects had a negative impact.

Two different levels of investigations will be carried out, one using the bibliometric indicators and one based on detailed analysis of the content. A number of central lines of investigation are pursued here:

(1) We track down the intellectual foundation that led to the development of this publication by analysing its references, and in some cases, the references of its references. We investigate (or at least speculate based on the existing evidence) where the concept of "escape panic" has stemmed from in this publication, or what has been the main origin and foundation of describing the characteristics of escape panic as described by the authors.

(2) We investigate how the language and terminologies used in this paper has influenced the general terminologies of crowd dynamics. We look at the language used in the field before and after this publication in order to conjecture on its influence on terminology choice in this field. What was the sentiment around the notion/terminology of "crowd panic" (as one example terminology) before this publication and how did it change afterwards?

(3) Helbing et al [1] laid out a number of assumptions that characterise "crowd panic". Some of these characteristics have been empirically tested, using various experimental methods since then, and especially in recent years. We contrast these assumptions with the body of empirical evidence that has accumulated since the date of Helbing et al. [1] publication and conclude whether this body of evidence is generally in support of those conceptual characteristics.

(4) Following the introduction of the social force modelling concept, Helbing et al. [1] undertook a range of numerical simulation experiments and drew a series of (in some cases, counterintuitive) conclusions that have permeated extensively into the literature of crowd dynamics (and even in the minds of the public). Many scholars have tried to replicate those phenomena (e.g., faster-is-slower, obstacle effect) and many think of those phenomena as modelling benchmarks, meaning that, if a model does not produce such phenomena, then it cannot be considered as an accurate crowd motion model. We contrast those numerically simulated phenomena with the body of studies that have replicated those phenomena in experimental settings since then. We investigate whether or not those findings have lived up to experimental scrutiny. In some cases, we provide potential explanations as to why some of these numerical observations have failed experimental replication.

Overall, this study provides a comprehensive, evidence-based, and objective dissection on the the extent of impact, knowledge foundation, accuracy of terminologies, and validity of the underlying assumptions and its numerical observations of the above reference. This helps us determine whether the field should continue the current course heavily influenced by this publication, or that we need to consciously call for a paradigm shift and correct some of the previous trajectories that the field has followed.

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Towards the Application of Evidence-based Evacuation Training

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Evacuation training is becoming an item of increasing research interest over the past years and in the fire research domain it is recently heavily influenced by the application of technology, like virtual reality (VR), augmented reality (AR), and serious gaming (SG), though the practical merits of evacuation training and their applicability often remain unclear [1]. While there seems to be a generic consensus on training being beneficial, research on the topic varies significantly in its characteristics (e.g., building environment, population, training method, educational contents and strategy, effectiveness metrics, etc.) to currently draw generalisable conclusions that could allow a quantification of training effects [2]. Understanding these benefits and effects in detail would allow to pursuit performance goals, and evacuation training to become a reliable safety tool rather than an amendment to safety strategies.

We argue that the application of evidence-based training requires us to not only understand the effectiveness of evacuation training, but that it needs also to consider how training can effectively be administered, delivered, and measured. A clear methodology to measure and assess the effectiveness of evacuation training is, in fact, currently missing [2]. Evacuation training is generally governed in national regulatory frameworks usually solely prescribing evacuation drills [3]. Consequently, evacuation training is frequently perceived a nuisance producing to the main drawbacks of evacuation drills being lack of engagement and its disruptiveness [4] - although partially related to insufficient organisation [1]. It is thus vital to understand the perspectives towards evacuation training among those who are going to be at the focus of it, when investigating the effectiveness and assessment of evacuation training. This way it can be ensured that resulting strategies make sense to those involved and hence would find acceptance and practical use.

This work first provides an overview of existing training methods, expected knowledge transfer, and knowledge retention. Training effects and evaluation metrics are then reviewed based on existing literature, looking at the relationship between training target, method to deliver the training, and the effectiveness metric adopted. To investigate on the attitudes towards evacuation training among the general public, a survey study is also carried out across multiple countries. The aim is to gain a broader understanding of people's experiences with fire evacuation training and their attitudes towards it as a risk mitigation strategy.

Results from the questionnaire will be statistically analysed with the goal to create insights to feasible, effective strategies for evacuation training and its assessment in the future. This knowledge will subsequently be used to inform the design of future behavioural experiments testing different training and assessment methods for their effectiveness.

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Behavioral repertoires in crowds: Theoretical and practical implications

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This social psychological study is about discrete behavioral repertoires in crowds. By analyzing the performance of co-ordinated actions in a crowd, we can identify large or small groups inside it. This talk will focus on the practical and theoretical utilities of identifying such distinctive subgroup behaviors.

We analyzed the data from a series of experimental runs in which large groups of participants (N=80-100 for each run) simulate the entrance of a concert hall. They gather in a holding area and then pass through a bottleneck to go to the concert. Their exact location is monitored from three ceiling-mounted cameras. Behind the bottleneck, participants rate the overall experience on a feedback terminal. Afterwards, they fill in a short questionnaire. Questionnaire data and individual trajectories can be combined via Aruco codes on participant heads. In total, 45 experimental runs have been conducted under different conditions, including motivation (low/high) and various other factors such as aspects of geometry. For this presentation, we focus on four runs, two with high, two with low motivation while keeping the other factors neutral and constant.

With a detailed observational analysis, we identified discrete sets of co-ordinated actions which tend to be performed by (large) subgroups in the crowd, particularly when it is in motion. Moreover, we can identify different forms of social interaction or co-ordination in smaller units (e.g., dyads, triads). Finally, we see instances of individuals disengaging themselves behaviorally from the otherwise co-ordinated crowd. Together, this collection of behaviors of large groups, small groups and individuals can be combined into an *ethogram* (a list of all possible behaviors which we see as co-ordinated action in this particular ecology).

Fig. 1: Snapshots of participants moving towards the bottleneck (left: second 16, right: second 22), showing large groups (yellow), individuals (green), small groups (red), and their respective behavior.

These repertoires mark out relatively homogeneous entities in crowds (large groups, small groups) and allow us to study their psychological characteristics from the perspective of participants, based on analyses of questionnaires and feedback terminal data. We can also study the temporal development of and transition between repertoires. These tools make it possible to identify shifts in social units relating to changes in behaviors within the experimental procedures.

The talk concludes by reflecting on the theoretical and practical utility of this analysis for the fields of social psychology and pedestrian crowd dynamics. Theoretically, this analysis informs us about the processes that can underpin crowds' performance of co-ordinated action, such as social identity, emergent norms or imitation. Practically, it broadens our understanding of the behavioral co-ordination mechanisms that lead to pedestrian behaviors, both less (e.g., queuing) and more risky (e.g., pushing, running).

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Quantifying Leader-follower Relationship in Pedestrian Crowd Using Transfer Entropy

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Many scenarios, including fish schooling, bird flocking, and pedestrian crowds, are thought to exhibit collective patterns. It is believed that these collective patterns emerge as a result of individuals adjusting their movements in response to perceived local conditions [1]. Unveiling the mechanism of local individual interactions helps explain the underlying trend of the movement of the whole group. This study suggests using a transfer entropy (TE) method to quantify one of the most representative local interactions, i.e., leader-follower (L-F) relationship in pedestrian crowd. TE is an information-theoretic and model-free approach, introduced by Schreiber [2] for measuring the asymmetric information transferred from one system to another. In this study, we applied TE to pedestrian system to quantify how much uncertainty is reduced in predicting the next state of a pedestrian if knowing the past movement information of another pedestrian, over prediction based on the history of the first pedestrian alone. The movement information of velocity time series was used for calculating TE. The roles of leader and follower were distinguished using net TE that measures the difference between one's output TE and input TE. A pedestrian tends to follow the leader who outputs the maximum net TE to him/her over a threshold value. We examined the undeclared L-F relationship in the recorded experimental videos published by Forschungszentrum Jülich (Pedestrian Dynamics Data Archive, DOI: 10.34735/ped.da), including three typical pedestrian traffic scenarios: an unidirectional flow in a straight corridor, a turning flow in a "L-shape" corridor, and a four-directional flow in a cross corridor. The results showed that the L-F relationship was prominently measured in the situations that pedestrians changed their moving direction; for example, the leader distribution is mainly in the corner area for that turning flow and around an obstacle in the four-directional flow, as shown in the Fig.1. We found that the influence radius (or interaction domain) and TE threshold value were two crucial parameters affecting the TE performance in identifying L-F relationship in pedestrian crowd. The main contribution of this study is providing new insights and solutions to quantify the L-F relationship and distinguish the driving and responding elements of pedestrian crowd in the process of movement.

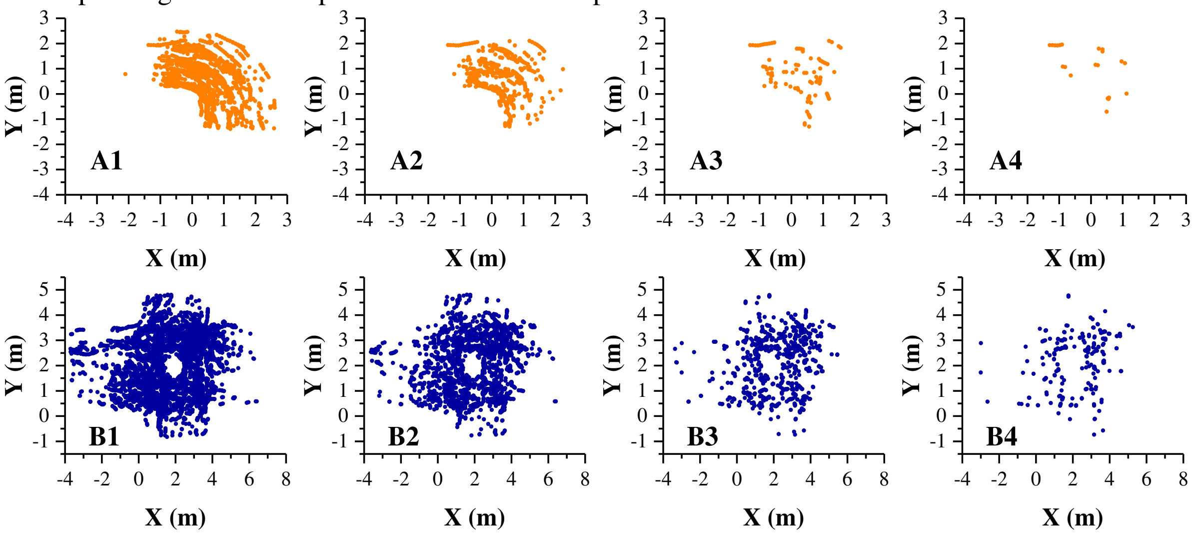

Fig. 1. Leaders' positions distributed in the turning flow (A1-A4) and the four-directional flow (B1-B4) under different TE threshold: 0.8, 0.9, 1.0 and 1.1 for A(B) 1-4 respectively.

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Investigating Psychological Processes Underlying Train Boarding Efficiency and its Importance for Nudging

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Research on train boarding efficiency focuses predominantly on the physical modeling of pedestrian dynamics and little is known about the underlying psychological processes of passengers. Analyzing tracking data from 3728 boarding events at Utrecht Centraal, The Netherlands, we found that with increasing numbers of boarders waiting at the door, the width of the deboarding corridor decreased, see Fig. 1. This in turn lowered deboarding efficiency. However, such data alone cannot explain why boarders exhibit this behavior, and must be augmented with psychological data and theories reflecting how people strategize in these complex situations.

Therefore, we conducted two focus groups, each with 6 experienced travellers. We found that boarders compete for resources—in particular, seats—and strategize more in busy, more competitive situations; constantly gathering new information and trying to adapt to the situation to fulfil their goals. While they recognized social norms such as waiting for deboarders to leave the train before getting in, participants experienced little to no regulation and sometimes broke the norm to achieve their goals. These findings thus provide insights into why boarders might narrow the deboarding corridor and unintentionally slow down the deboarding process.

Understanding these underlying motivations is important and goes beyond considering boarders as mere particles. Considering aspects of agency are important before employing nudging interventions to improve boarding efficiency. Nudges in public space are often not effective, because implementers do not rely on behavioral theories, do not correctly identify cognitive/heuristic biases (i.e. mental shortcuts), or because of a mismatch between the nudge and the cognitive behavior it targets [2]. In complex situations, where people are constantly updating their information and making new decisions, people often rely on heuristics. Knowing these heuristics and strategies can inform the design of effective nudges. Social norm theory and interdependence theory may help to explain how people make decisions when outcomes (e.g., having a seat) are dependent on the decision-making of others, and to update social force models used in pedestrian dynamics by incorporating individual goals, strategies, norms, and dependence on others. These in turn can be used to confirm explanations of psychological processes in a simulation model.

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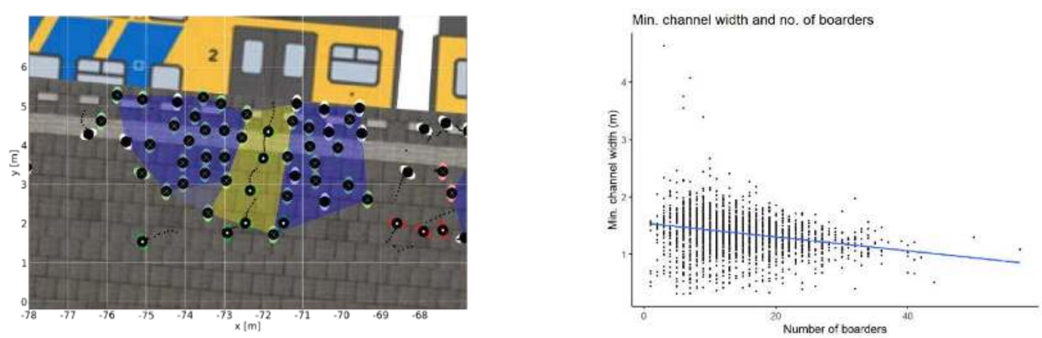

Fig.1.a) Overhead image of a boarding event using real-life data. Blue region is the space occupied by boarders. Yellow region is the channel for deboarders b) Channel width as a function of the no. of boarders waiting to board

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Energy, carbon and environmental impacts of pedestrian flow management configurations in train stations

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Taking the stairs may be good for your health, but is it the same for the environment? Train station designers and architects often wonder if it is better to implant multiple escalators in stations, for comfort and efficiency, or if it is better to use stairs. In a small station, the choice between an escalator and a pedestrian ramp is not trivial: the former will consume electricity throughout its lifespan and require constant maintenance, whereas the latter uses significant amounts of matter and space within the station. Making comfortable spaces requires materials and energy, however this more attractive space may incite a modal shift from cars to trains, which has a positive environmental impact.

In this paper, we use the EMC2B method (energy, matter, carbon, climate, biodiversity) to assess the environmental impact of various train station elements: escalators, elevators, stairs, ramps, and spaces. We also consider the impact of these elements on comfort, health, pedestrian flow, and station management. The impacts are estimated for three typical cases: a small, a medium and a large train station. We also attempt to compare the overall gains and losses by considering the environmental impact of the construction in train stations in relation to the environmental benefit of the modal shift from cars to trains.

We notably find that in the case of a small station, a pedestrian ramp designed for accessibility can have a more important carbon footprint than an elevator, despite the energy needed to run it. More globally, we show the different impacts of the typical choices made when designing three typical stations. Finally, we compare these local environmental impacts to the potential global positive impact on modal shift and show the importance of maintaining a certain level of comfort in certain stations.

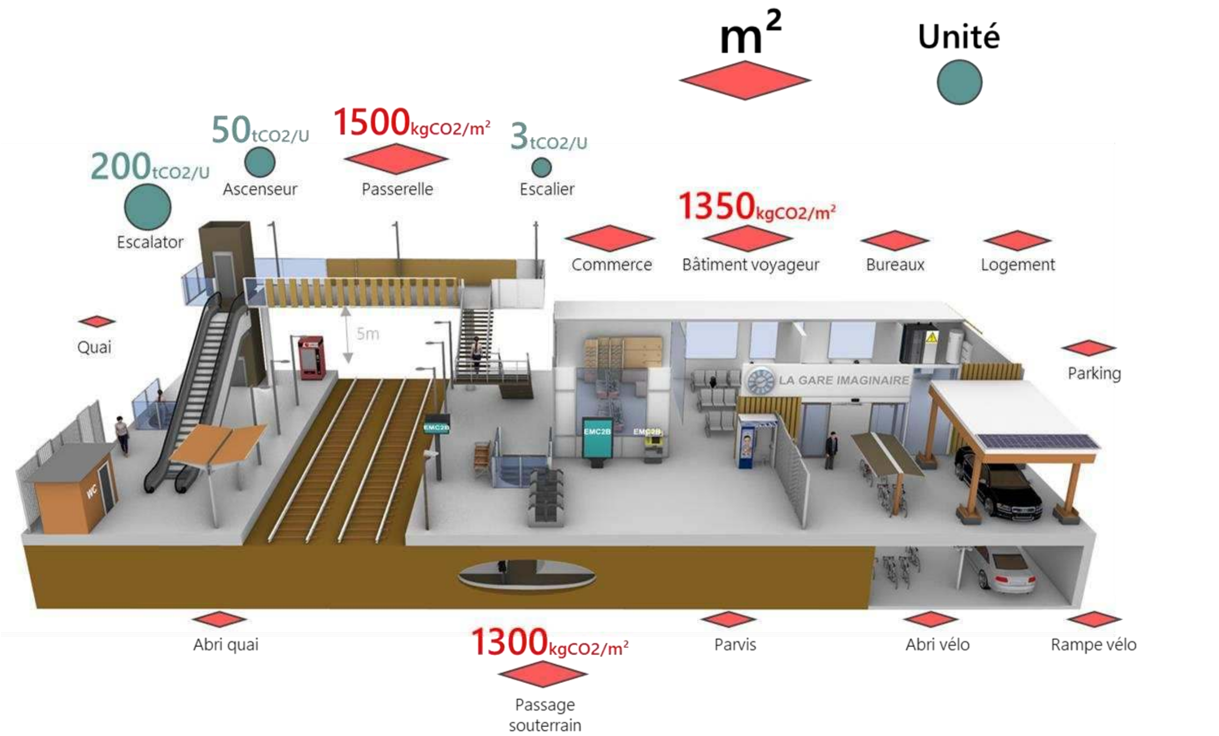

Figure 1: Carbon footprint estimation of different station elements.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Social behaviour and communication in evacuations: A systematic review

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Most modern agent-based models (ABMs) of evacuations involve coordination between evacuees [e.g., 1]. However, the assumed reasons for behaviour and portrayal of that behaviour can be oversimple. They particularly neglect the importance of group relations among the evacuating agents themselves, and the relations between the evacuating agents and agents providing evacuation instructions. Research from social psychology suggests that people communicate with one another when evacuating, and evacuee response is impacted by the source of the information about the emergency and the way it is communicated [2]. As the first step of our project 'Simulating the impact of first responder strategies on citizen adherence in emergencies', we systematically reviewed literature of evacuation ABMs to categorise how they implemented agents' social interactions and communication during emergency evacuations (including staying in place or reaching a safe area), to highlight the approaches and identify the key variables that the models addressed. Our review questions were: 1) How do evacuation ABMs simulate social interactions and communication approaches between agents? 2) What are the key variables addressed in these models?

We searched Web of Science and ScienceDirect for articles published between 2010 and 2022 to capture the current state of the art. Articles were included if they described: 1) the simulation of public response to emergency scenarios, 2) the simulation of information exchange between agents during evacuation, and 3) the simulation of social behaviour during evacuations. The search generated 568 articles, with 85 articles included in the full text review based on their relevance to our review questions. We then created categories of the nature of the agents' social interactions. The categories included: 1) basic collision avoidance, 2) following behaviour, and 3) degrees of social influence. Of the 14 articles which incorporated communication between agents, communication was operationalised: 1) by agents creating trails of information in the environment, 2) by agents sending information to others within a set distance around them, 3) as information-sharing among social networks, or 4) through external communication shared to agents in certain spatial areas. We also present the most common independent and dependent variables used in the literature and showcase emerging trends of focus over time.

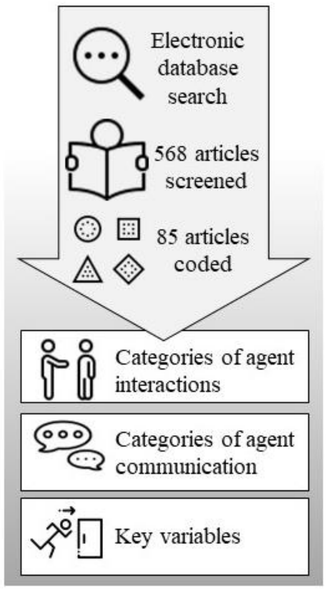

Figure 1: Search and categorisation process

Overall, we provide an overview of current evacuation ABMs regarding agent communication and evaluate the sophistication of their assumptions considering findings from empirical research on public response to emergencies. We further recommend evidence and concepts from social psychology to inform future evacuation ABMs and discuss the availability of existing commercial software to implement these.

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Keynote - Friday, 30th of June

Slow and Fast Pedestrian Dynamics

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In this presentation, we will discuss the physically-related phenomena arising from different possible states of pedestrian dynamics (Fig. 1). We will explore some open questions, such as: Is the fundamental diagram a complete description for all possible states? How much should we trust pedestrian models?

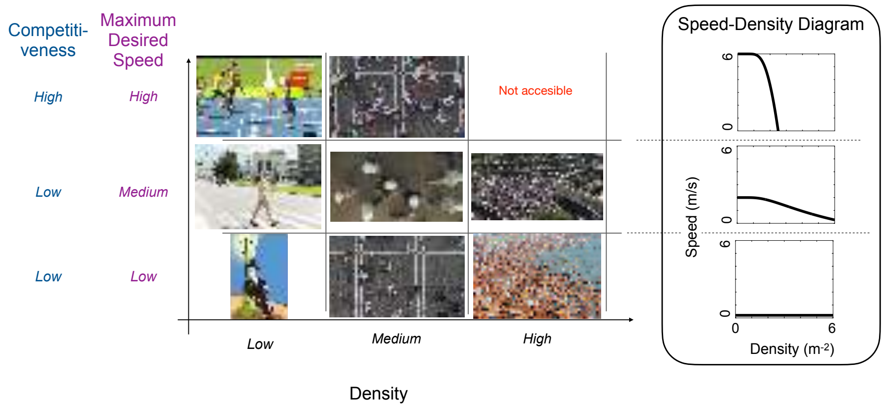

Figure 1: A possible classification for a variety of pedestrian systems.

To underscore the significance of experimental data and as an illustration of the diverse phenomena, we will examine outcomes pertaining to three different regimes.

Firstly, we will explore collision avoidance mechanisms. Real trajectory data will be utilized for calibrating and validating collision avoidance simulations, including the application of a data-driven simulation approach [1]. Additionally, we will present a variant of the Contractile Particle Model [3] that incorporates asymmetry and an avoidance mechanism.

Secondly, we will investigate pedestrians fleeing from real danger at high velocities. We will delve into the empirical study of the running of the bulls in Pamplona, Spain [2]. These data reveal that high desired speeds and high densities are incompatible, prompting us to question the need for differentiation between competitiveness and high-speed. While these concepts are related, we will explore why they should be treated as distinct.

Finally, we briefly revisit the journey from the prediction of the "faster(stronger)-is-slower effect" at bottlenecks [4] to its experimental verification. We begin with the exploration of simpler systems, such as a silo containing glass beads on an incline [5], and gradually progress to more complex scenarios involving vibration-driven vehicles and sheep. Ultimately, experimental validation was achieved by conducting human egress drills under both normal and competitive conditions [6].

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

High-statistics real-time pedestrian tracking on stairways and escalators

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Staircases and escalators play a crucial role in pedestrian traffic through large public facilities. As these facilities become increasingly trafficked, we observe that escalators and stairways are notorious places for crowd congestion and pedestrian accidents. In fact, 30% of the pedestrian accidents reported in 2021 at Dutch train stations originated on the escalators Ref. [1]. To address these safety and efficiency issues it is crucial to study the dynamics of crowds on inclined surfaces such as stairs, escalators, and ramps. However, most optical tracking systems need additional visual markers, e.g. colored hats, for accurate tracking on non-flat surfaces. Existing research is therefore mostly constrained to studying the pedestrian dynamics in experimental laboratory setups or by using only small, manually tracked, trajectory data sets e.g. Ref. [2].

In this contribution, we study in-depth the pedestrian dynamics on the escalator and staircase. We measure relevant observables, such as the walking velocity, pedestrian flux, and crowd density, and investigate their mutual correlations e.g. the fundamental diagram. Moreover, we research pedestrian choice behavior concerning the staircase and escalator thereby generating valuable insights into the facilities' usage patterns. Studying these dynamics was only possible because we improved the algorithms used for localization and tracking and thereby tackled challenges such as non-trivial perspective correction. We applied these novel methods to images captured by state-of-the-art stereoscopic sensors. The setup continuously monitored a highly-trafficked staircase inside a real-life Dutch train station since 2020. This enabled us to retrieve a unique high-statistics and privacy-preserving set of pedestrian trajectories on the escalator-staircase system Fig. 1.

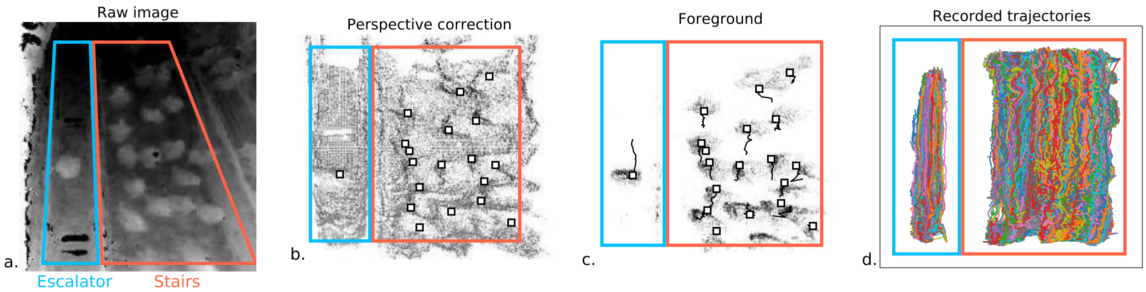

Figure 1: Pedestrian tracking on a highly trafficked real-life escalator (blue rectangle) and staircase (red rectangle). Output of the subsequent image processing steps: a.) Recoreded raw image, b.) output after perspective correction, c.) output after background removal d.) retrieved pedestrian trajectories.

Keywords: pedestrian tracking, crowdflow, computer vision, stairs and escalators

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Using Virtual Reality to assess the impact of urban elements on pedestrian wayfinding behavior and well-being

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Finding one's way in urban environments can be stressful [1]. Virtual reality (VR) provides opportunity to study pedestrian wayfinding behavior in different virtual environments with high experimental control and accurate data collection [2]. Combined VR with physiological sensors, it is possible to measure pedestrians' well-being and provide more insights into the wayfinding process. Although more studies have employed VR to investigate pedestrian wayfinding behavior, it is unclear how to reduce the related stress when they try to find their way.

This paper employed VR and a physiological sensor to study the impact of different urban elements on pedestrian wayfinding behavior and well-being. We chose to investigate the outdoor-indoor wayfinding transition, in the context of a train station - as stress is already generated by reaching the station, finding a platform, and catching a train on time. Spatial cognition is also a stress trigger as the participant has to learn a new environment when entering the station from outdoor. Three urban elements include greenery, water, and leading pavement that are known to reduce urban stress. These elements are placed either indoor or outdoor to assess their effect on pedestrians' wayfinding performance and comfort level. In total, four VR scenarios were designed. During the experiment, participants need to complete a wayfinding task for every scenario, namely going from outdoor the station to reach a platform inside the station. Afterward, participants need to fill in a questionnaire. The VR experiment was approved by the Human Research Ethics Committee of Delft University Technology (Reference ID 2079).

In total, 35 participants took part in the VR experiment. A set of behavioral, physiological, and user experience data was collected. It includes movement trajectories (x,y coordinates), timestamp (s), eye tracking (x,y,z coordinates), heart rate (bpm) and surveys' answers. Figure 1 shows the heart rate along the participants' movement trajectory. Figure 2 shows the gazing distribution in the virtual environment. The qualitative and quantitative data collected in this research allowed an in-depth analysis of behavioral and physiological features, to exhaustively understand and assess pedestrians' wayfinding behaviors and well-being. The results showed a better comfort and wayfinding performance for the scenario that displays urban elements both indoor and outdoor. During the conference, the experimental method, data analysis and findings will be presented.

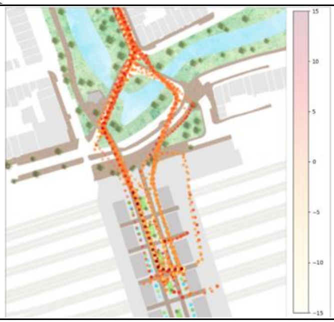

Figure 1: Heart rate mapped on participants' trajectories

Figure 2: Eye-tracking mapped in 3D in VR

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands - June 28-30, 2023

Congestion Number analysis of cross-flow dynamics: experimental data and simulations

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We recently published two works on the dynamics of two orthogonally crossing pedestrian flows based on a series of controlled experiments (Fig. 1), in which we varied the pedestrian density initial condition. In [1], we defined a few empirical observables, such as the average density in the crossing area, the velocity distribution, the relative position of pedestrians in the same and in opposite flows, and shoulder orientation, to analyse how the density conditions affect the cross-flow dynamics. In [2] we proposed a hierarchy of simulation to reproduce the cross-flow dynamics, and used the aforementioned observables to compare such models and understand which features are necessary to reproduce the observed dynamics. We verified that the most complex model, using detailed collision prediction and an asymmetric body, outperformed the more simple ones. At the same time, we verified that using a detailed computation of possible collisions (even adopting a circular body shape) is the most important component of the model, while the actual description of the body asymmetry is useful only at very high density.

We also recently published a manuscript [3] in which we proposed a "Congestion Number" (CN) to evaluate the state of the crowd. The CN is defined by measuring the gradient of the rotor of the crowd velocity field ("Differential Congestion", DC) and comparing it to a theoretical "maximum value" EDC

$$CN(\mathbf{x}) \equiv \frac{DC(\mathbf{x})}{EDC(\mathbf{x})}, \quad DC(\mathbf{x}) \equiv ||\nabla[(\nabla \times \mathbf{v})_z(\mathbf{x})]||. \tag{1}$$

It is shown that $CN \ll 1$ corresponds to a crowd with a regular and safe motion, while $CN \approx 1$ indicates the emergence of a congested and possibly dangerous condition.

In this work we join such contributions, by analysing the experimental and simulation results of [1, 2] using the CN metrics proposed in [3]. A preliminary result showing a comparison between the CN time evolution of two experiments is shown in Fig 1. The maximum CN value results to be ≈ 0.4 which is interpreted as an "intermediate" congestion.

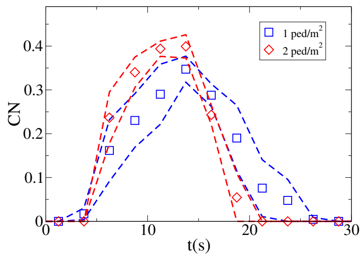

Figure 1: Left: screenshot of the experimental setting. Right: time evolution of the maximum CN value for two different density conditions.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Interaction within a highly motivated crowd in bottleneck experiments

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In recent years, several experiments have been performed with highly motivated crowds at bottlenecks, e.g. [1, 2]. Most of these studies focus on clogging or transversal waves. In the EU-funded *CrowdDNA* project [3], we aim to get a 3-dimensional view of the system and to link macroscopic and microscopic measurements to individual limb movements. In this context, situations with high densities are of particular interest to us. Here we present the analysis of bottleneck experiments [4] in which we captured the full body motion of several participants to gain new insights into how people move and interact with their bodies in a dense crowd. In order to achieve different density levels and different levels of physical interaction, the degree of motivation of the participants was varied in three stages being 'normal', 'hurried' and 'full commitment'. The announcement of the latter was "You are in a crowd where everyone wants to pass through a door as quickly as possible and pushes their way through. You yourself do everything you can to get to the front and through quickly as well." Further experimental parameters being varied were the number of participants and the width of the bottleneck opening. One focus is on the 0.7 m opening width, as this is narrow enough to prevent two people from walking through at the same time, so we expect blockages and clogging to occur. The acquired datasets include individual head trajectories that were extracted with *PeTrack* [5] from overhead video recordings (Fig.1-a). Furthermore, in each run up to 20 participants were equipped with inertial motion capturing (MoCap) suits *MVN Link* [6] to record their 3D fullbody motion within the crowd (Fig.1-b). Besides an analysis of the density (Fig.1-c) and of waiting-time/target-distance relations, we will analyse collective motions, e.g. by velocity polarization. Furthermore, we aim to analyse motion propagation and interaction within the crowd based on the trajectory and MoCap data.

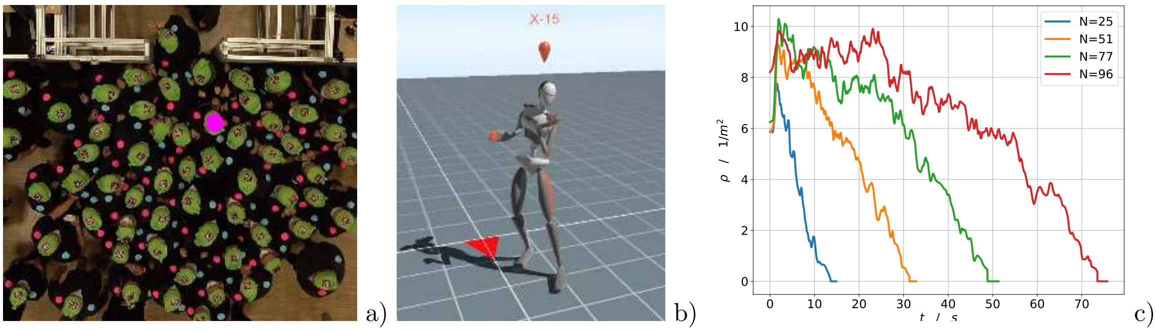

Figure 1: *a)* Bottleneck experiment at 0.7 m width under 'full commitment'. *b)* Visualization (Software *MVN Analyze*) of MoCap data acquired in the crowd for the person with a pink dot in a). *c)* Density in front of the bottleneck: width = 0,7 m, 'full commitment', different number of participants N.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

A comprehensive approach to model pedestrian wayfinding behaviour in a multi-story building

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Understanding pedestrian wayfinding behavior in buildings under normal and evacuation conditions is vital to pedestrian safety. Pedestrian wayfinding in a building refers to the decision-making process that consists of (1) choosing a route, (2) acquiring information from the environment, and (3) accordingly navigating to a destination [1]. A number of studies have investigated wayfinding behavior from either modeling or experimental perspectives ([2–6]). From a modeling point of view, existing studies often simplify pedestrian wayfinding behavior by modeling only one level of the above-mentioned metrics. From an experimental perspective, most studies focused on pedestrian wayfinding behavior on a single level (i.e., horizontal level) or in simplified environments due to the constraints regarding experimental control, data collection, and ethical and financial restrictions of traditional experimental methods.

To fill this research gap, this paper focuses on modeling pedestrian wayfinding behavior in a more comprehensive manner in which the above-mentioned three levels of metrics are included. Our hypothesis is that the same set of personal, infrastructure, and environmental factors affect indoor pedestrian wayfinding behavior on three levels, namely route choice, wayfinding performance, and observation behavior. Data from a VR experiment featuring pedestrian wayfinding behavior in a multi-story building (see [7]) was used to develop four distinct sets of models. The VR experiment included four different wayfinding assignments with increasing complexity, namely (1) a within-floor wayfinding assignment, (2) a between-floor wayfinding assignment (i.e., across the horizontal and vertical level), (3) a more complex between-floor wayfinding assignment, and (4) an evacuation assignment. Quantitative data featuring pedestrian route choice, wayfinding performance, and observation behavior is collected via the VR system. Qualitative data regarding personal characteristics and perceptions is collected via a questionnaire. This unique data set allows us to model pedestrians' wayfinding behavior that covers the above-mentioned metrics.

This paper employs two types of discrete choice models (i.e., MNL and PSL) to model pedestrian route choice behavior, and multivariate linear regression models to model the overall wayfinding performance and observation behavior (e.g., hesitation behavior and gazing stability). This paper adds to the literature by comprehensively modeling pedestrian wayfinding behavior in multi-story buildings for the first time. At the conference, we will present the findings of the current paper.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

The impact of illumination on pedestrian route choice and walking speed using virtual reality

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Crowd management gained in importance over the last decades for various reasons. For example, the number of mass events for religious, sportive or festive gatherings is increasing. As a consequence, urban spaces are becoming more crowded, while these spaces are not always suited to manage these increasing crowds sufficiently.

Nudging is one of the methods to deal with large crowds while maintaining the efficiency of the environment and the comfort levels of the pedestrians. Non-intrusive crowd management measures are considered nudges, i.e. measures that alter pedestrian behaviour without the participants realizing that they are being managed. Examples of these non-intrusive crowd management measures are aural stimuli, such as background music and metronomes, and illumination, for example illumination brightness and illumination colour. This research is interested in the particular impact of both illumination brightness and illumination colour on the pedestrian movement dynamics and choice behavior.

The relationship between illumination and pedestrian behaviour is intuitively strong, but there are only a few studies presented in the state-of-the-art literature that features results on this relationship. Earlier studies showed that the majority of pedestrians prefer the brighter path over the darker path during both normal and emergency conditions (Taylor and Socov, 1974; Vilar et al., 2013). Next to that, Hidayetoglu et al. (2012) showed that lower brightness levels were evaluated more negatively compared to the brighter levels. In terms of the illumination colour, the state-of-the-art literature identifies that pedestrians prefer to follow green running lights over the baseline without running lights when asked to choose the safest path (Künzer et al., 2020). The current insights about the impact of illumination on movement dynamics and choice behaviour are inadequate to effectively utilize illumination as a means for crowd management.

This study presents a large scale virtual reality (VR) experiment that aims to enhance our understanding of the impact of the brightness and the colour of illumination systems on pedestrian movement and choice behaviour. Participants are asked to walk through a virtual environment using a head-mounted display VR system with free motion. They need to make a choice between two almost identical paths in terms of visual appearance for every scenario. In each scenario, the lighting conditions of the two paths are varied individually, either the illumination brightness is changed on the two paths or the illumination colour. The study consists of 50 possible scenarios featuring 5 different illumination colours and 5 levels of illumination brightness, both of them leading to 25 scenarios. The experiments are designed with a combination of between-subject and within-subject as participants are not able to perform all scenarios. The experiment is conducted with a heterogeneous participant population. During the experiment, walking behaviour, choice behaviour and gazing behaviour is recorded. Afterwards, all participants answer an extensive survey featuring questions on personal characteristics, prior gaming and VR experience, and VR immersion (i.e. realism of VR environment, simulation sickness and feeling of presence within VR environment).

Before the VR experiment is conducted, a large pilot is performed to understand the participants' perception of illumination in the virtual environment. The aim of the pilot is to translate various illumination colours and brightness levels from real indoor environments to the virtual environment with accuracy, i.e. to ensure that the participants perceive the illumination conditions in VR as they would experience them in real-life. If the participant needs to be exposed to 1000 lumen, the aim is to ensure the participants perceive 1000 lumen in VR instead of emitting 1000 lumen in VR. The same analysis holds true for the perception of illumination colour. This pilot consists of multiple tests in real-life and the VR environment to understand the participants' perception.

The design and piloting of the experiment is currently ongoing. This study is going further than any of the earlier studies in terms of understanding the impact of the illumination conditions on the pedestrian movement dynamics and choice behaviour due to our systematic approach. At the PED conference, the first results of the VR experiment including the pilot are presented. The main question that we will answer at the conference is: 'To what extent do the illumination conditions influence the choice behavior and overall walking speed of participants?'

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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The Unwavering Counter-Clockwise Movement in humans - A Three-Act Study -

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From the synchronized steps of marching soldiers to the fluid grace of crowds in concerts, human motion holds a certain allure that has captivated the attention of scientists for a long time. The intricate *dance* of a crowd in motion has proven to offer a rich phenomenology, where each step or turn seems to self-organize like a well-choreographed performance. Interestingly, a remarkable pattern has recently come to the forefront in the realm of pedestrian dynamics - a consistent tendency for crowds to start rotating in the counterclockwise (CCW) direction if you asked them to walk freely within a certain enclosure [1].

Such curious behaviour was initially noticed during the course of lab experiments aimed at analyzing physical distancing between pedestrians (Fig. 1a,b). This serendipitous discovery triggered further research to uncover the underlying mechanism behind the phenomenon. It was hypothesized that the *symmetry-breaking* in the rotation might be caused by the interplay between pedestrians and walls, combined with the natural turning preference of right-handed individuals (who constitute the majority in the experiments) to make *left* turns when facing a wall.

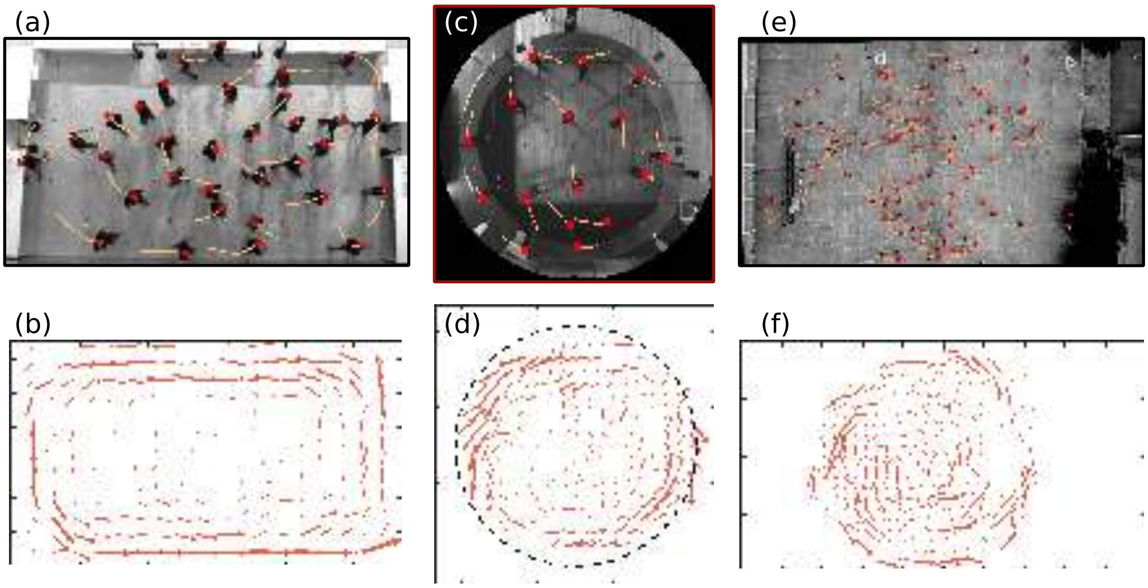

Figure 1: Panels (a), (c), and (e) display three different snapshots taken during the course of the experiments described in the main text. In (b), (d), and (f), the corresponding mean velocity fields are shown. In all of them, regardless of the experimental conditions, the counterclockwise rotation is always present.

To experimentally ascertain the validity of the aforementioned hypothesis, a second experiment was performed, but this time considering the turning preference of the participants within the enclosure (Fig. 1c,d). Surprisingly, the results demonstrated that it was not possible to force the development of clockwise rotation even if all individuals had a preference to turn *right* when interacting with a wall. Our last (third) experiment aimed to determine if the walls really played a role in the emergence of this self-organization process. To do this, we asked a group of students to walk freely (i.e. without following a particular direction) in a $(50 \times 40\, m^2)$ schoolyard. Once again, it was evidenced that, even in open areas where the interaction with the walls could be neglected, the CCW *symmetry-breaking* persisted (Fig. 1e,f).

These three experiments have provided crucial insight into the enigmatic topic of vortex formation in crowds and the underlying mechanisms that drive this captivating display of motion. Everything seems to indicate that we are confronted with a social convention which will require further research.

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Effectiveness of evacuation signs: The evidence from the functional near infrared spectroscopy and eye-tracking study

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Evacuation signs play a vital role in guiding pedestrians to the safety exits[1]. The attention and cognition process of evacuation signs by pedestrians reflect the guiding effectiveness[2]. The objective of this study is to examine the activity in the prefrontal cortex (PFC) and virtual-processing of evacuees during the controlled sign decision-making evacuation drills by using functional near-infrared spectroscopy (fNIRS) combined with an eye-tracking device. The influence of the color (red, green and blue) and the content (running man, flame and arrow) is mainly focused on. The results show that left ventrolateral prefrontal cortex (L-VLPFC) is significantly activated when using green signs, while not activated for the red and blue. Besides, green sign makes it easier to find the sign location and to understand the guidance meaning. For arrow&flame sign and arrow&flame&running-man sign, L-VLPFC is evidently activated, while Frontal pole area (FPA) is dramatically activated for flame&running-man sign. Arrow&flame sign makes it difficult to identify the guiding direction and afford longer duration for eyes to fixate. In addition, through the analysis of PFC functional connectivity (FC), it is drawn that the number of statistically valid channels reflecting mental resources, in green sign guiding case is less than that in red and blue case. Also, the FC results show that the number of statistically valid channels in flame&running-man sign guiding case is significantly more than that in arrow&flame and arrow&flame&running-man case. The evidence above indicate that the green color and an arrow will improve signs' guiding effectiveness.

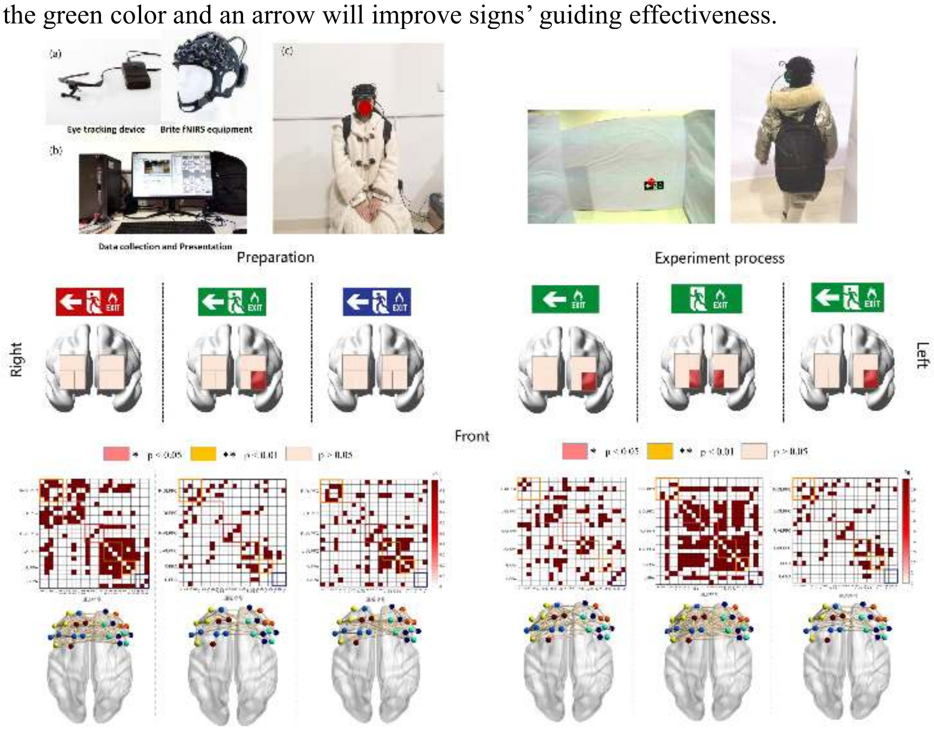

Figure 1: Experimental setup and results.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Factors influencing trade-off mechanisms in intersecting flows- Give way or Force gaps?

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Different strategies are used by people while walking to promote their progress in the desired direction of motion. Often, there is a conflict when multiple people have different goals to reach, and the flow is not segregated. Such conflicts can result in local disturbances within the crowd and in turn affect crowd safety. Predominantly, in such situations, people adjust their walking gait, modify their walk direction, wait for their turn to pass or in extreme cases force their way. Unlike the earlier understanding of crowd behaviour, where people were thought to behave irrationally and lose their identity [1], it is now accepted that people act rationally in a crowd [2], [3]. It is observed that people try to resolve conflicts through mutual understanding and reciprocating behaviour in a crowd [4], [5]. For instance, a pedestrian might swerve to their side to avoid collision with an opposite pedestrian. However, if space is not available for movement, it might require one of the pedestrians to stop and then proceed. In crowded scenarios, people might also find it difficult to find adequate gaps to pass. Therefore, this study explores pedestrian crossing behaviour in intersecting pedestrian flows using data collected from a religious gathering.

Figure 1: Snapshot of the study area showing intersecting flow of pedestrians.

Video data of pedestrians walking in Ujjain, during Kumbh Mela 2016 (Fig.1) is used to model the gap acceptance behaviour of pedestrians. A gap is defined as the time headway required for a minor-stream pedestrian to make a crossing manoeuvre. We model the number of gaps a pedestrian from a minor stream waits to cross a continuous major stream of pedestrians and explore the effect of gap-forcing behaviour on gap choice. The number of gaps a pedestrian n waits to cross is modelled as following a geometric distribution. Each instance is a binary choice situation, where the pedestrian either accepts a gap or rejects a gap. It is seen that young people are willing to wait for several gaps to cross over and move when compared to older people. When compared to females, males are less likely to wait for gaps to cross over. Gap forcing is found to be a significant variable implying that when an individual decides to move through a gap forcefully, their chances of succeeding are high. Interestingly, the number of gaps can also be treated as an indicator of the tolerance level of pedestrians. Therefore, pedestrian gap choice is an important aspect to be incorporated in pedestrian modelling and simulation and this study could provide useful insights into factors affecting such decisions.

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11[th] International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Evacuation of a hospital ward in Italy: lessons learnt from an announced evacuation drill

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Evacuating a hospital is certainly a complex operation presenting many issues linked to emergency procedures, need for assisted evacuation, staff/patient ratio, functional limitations in patients, etc.; therefore, a carefully thought evacuation plan is a needed step to address these issues [1]. In this context, evacuation drills (announced, semi-announced or unannounced) can play a useful role to 1) assess the current evacuation procedures in the hospital and 2) provide training [2]. The purpose of this work is to present a set of lessons learnt from a (relatively simple) announced evacuation drill performed in a paediatric unit of a hospital. This allowed investigating the behaviour of the ward operators involved (paediatrics staff) while managing the evacuation of the patients (figureheads) present in the hospital area affected by the simulated fire. The aim is to highlight the procedural issues and the limitations of simple announced evacuation drills and present lessons learnt concerning evacuation test procedures in hospital areas. In this exercise, the fire was assumed developing from an electrical apparatus in one of the rooms of the paediatric ward. Only one patient per room is admitted to the operating unit under study. To represent the usual working conditions in the rooms under consideration, there were a total of 3 bedridden patients with the following characteristics: 1 patient with suction connected to the monitor (room 1), 1 patient connected to oxygen (room 2) and 1 patient with continuous infusion on pump in progress (room 3). The start of the event was triggered by a simulated ignition of the monitor placed at the side of the patient. One of the operators noticed the smoke (a sign with a flame was placed during the simulation) caused by the fire and alerted the concierge staff, informing them about the event, its extent, the presence of patients and the location concerned. The ward staff proceeded to alert the others in the vicinity to set up emergency management measures (closing room doors and fire doors), to remove the patients and organise their tasks, and to lead them to the identified safe place, gradually closing the fire doors behind them. Once the patients, using the escape route, had been transported to the indicated safe place, the emergency was declared closed.

The first limitation investigated is the study of the implications of the use of figures rather than real patients during evacuation drills in hospitals. In this specific case, it should also be emphasised that in a hospital ward (especially a paediatric one) family members are almost always present; it would be therefore appropriate to consider during drills how occupant load and social influence may impact evacuation performance. The impact of considering announced vs unannounced simple evacuation drill concerning assisted evacuation in hospital wards is also discussed, ranging from feasibility and practical aspects to the validity of the behaviours observed. Possible lessons learnt during evacuation drills of this type are discussed (e.g., even during an announced drill it was possible to identify a mis-match between the expected procedures in place and the actual evacuation performance). Overall, this work is deemed to represent a starting point towards a better understanding of the advantages and limitations of simple procedural evacuation drills in hospital wards in which assisted evacuation takes place.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Video Analytics for Understanding Pedestrian Mobility Patterns in Public Spaces: The Case of Milan

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Nowadays, thanks to the recent developments of ICT tools for collecting traffic data in the urban environment, there is ever growing availability of videos regarding the nerve centres of cities (e.g., live streaming webcams, CCTV systems, etc.). This enables detailed analyses of public spaces and their users, for a better understanding of hidden mobility patterns as mentioned in Ref. [1]. Having a clear view of pedestrian dynamics can be very helpful for various applications in modern days such as urban planning.

The main objective of this research project is to characterise public spaces through a mobility study on pedestrian patterns analysed by means of video analytics (i.e., *object detection*, *crowd counting*, *pedestrian tracking*). Video analytics techniques through the evolution of machine learning and deep learning have introduced the automation of tasks that were once the exclusive purview of humans who manually identify and study different relevant behaviours in the scenes as described in Ref. [2]. The analysis focuses on the different types of pedestrian dynamics (i.e., time, space or social-driven behaviours) and on pedestrian route choices to obtain pedestrian utilisation profiles through observable behavioural parameters (e.g., density conditions, speeds, trajectories, etc.).

Research revolves around the case study of Piazza Duomo (Milan, Italy). A tracking-by-detection approach was chosen for the analyses conducted. YOLOv7, state-of-the-art real-time object detection model in computer vision, was used to detect pedestrians after being trained on a custom dataset and in order to handle pedestrian tracking SORT algorithm was considered. Pedestrian detections were geo-referenced for later analysis. Initially, the distribution of detections was analysed using QGIS software, and later, point pattern analysis and trajectory data mining were performed using Python analyses. The trajectory data mining part was aimed at clustering the trajectories in order to identify pedestrian utilisation profiles (namely, commuters and tourists). Secondly, group analysis was carried out to identify groups of pedestrians that might indicate some mobility patterns in the public space considered.

According to the results of our study, conducting analysis in crowded scenes can be challenging, both with a human eye and with video analytics techniques. Definitely, computer vision techniques can provide great advantages, especially in terms of time. Within the Urban Informatics discipline, the results of this research could support the definition of evidence-based/ parametric approach for regeneration projects of urban public spaces. Moreover, the proposed methodology could be of notable interest for the calibration/ validation of computer-based pedestrian modelling and simulation systems, and for further development of computer vision techniques.

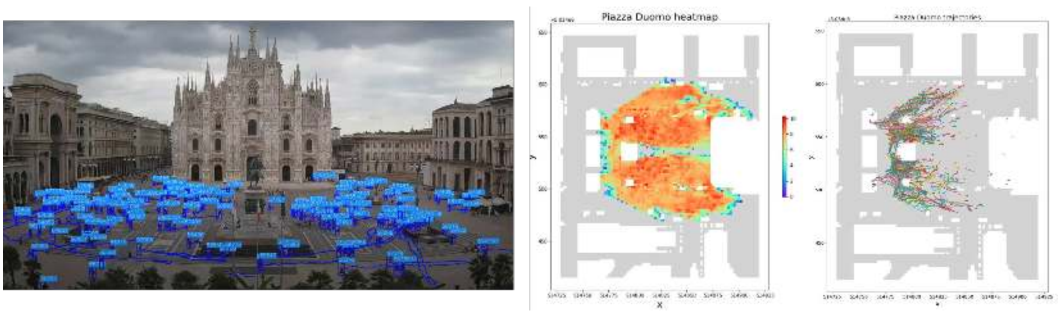

Figure 1: A screenshot from the analysed video about Piazza Duomo, with results about object detection, crowd counting, and pedestrian tracking.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Experimental Method to Estimate the Density of Passengers on Urban Railway Platforms

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The platform–train interface (PTI) is considered a complex space where most interactions occur between passengers boarding and alighting. These interactions are critical under crowded conditions, affecting the experience of traveling and therefore the quality of life [1]. The problem is that urban railway operators do not know what the density at the PTI is in real time, and therefore it is not possible to obtain a measure of the personal space of passengers boarding and alighting the train. To address this problem, a new method is developed to estimate the density of passengers on urban railway platforms using laboratory experiments. In those experiments, the use of computer vision is attractive, through the training of neural networks and image processing. The experiments considered a mock-up of a train carriage and its adjacent platform. In the boarding process, the results showed that the density using Voronoi polygons reached up to a 300% difference compared to the average values of density using Fruin's Level of Service [2]. However, in the case of alighting, that difference reached about 142% due to the space available for wheelchair users who needed assistance. These results would help practitioners to know where passengers are located at the PTI and, therefore, which part of the platform is more congested, requiring the implementation of crowd management measures in real time. To understand the scope of the method, you can view Figure 1.

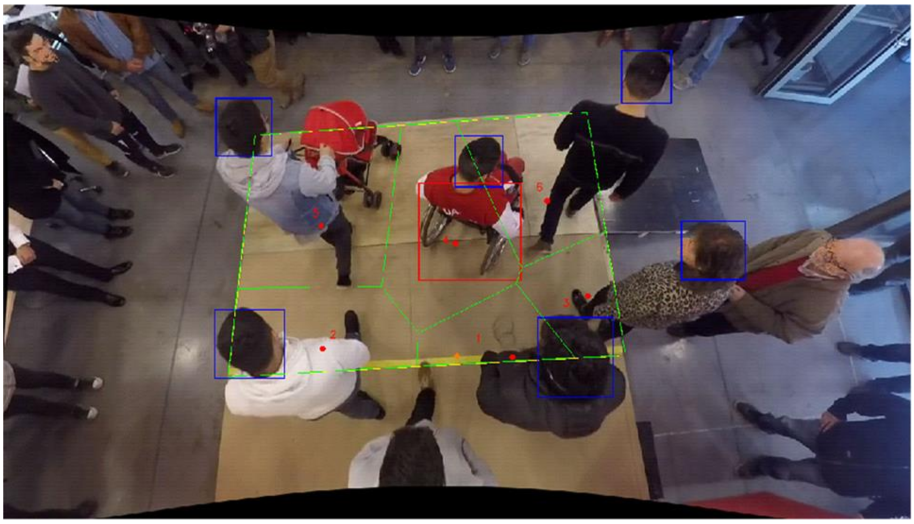

Figure 1: Method applied on laboratory experiment image. Green lines forming polygons are Voronoi Polygons, red dots are feet projections, orange dot is the reference point, and blue squares are detected heads.

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A simple optimization-based counterflow model for multi-agent navigation

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Considering pedestrian dynamics is essential for the design of usable and evacuation-safe venues like public buildings and railway stations. Modelling pedestrian behaviour and numerical simulations are one of the few tools available to logically analyse challenges in pedestrian dynamics. The proposed model in this work is an optimization-based approach to simulate pedestrian crowd movement in multi-directional flow, taking into account the challenges posed by pedestrian counterflow, where people walking from different directions can create conflicting situations that reduce the capacity of corridors [1]. In addition, in evacuation scenarios, an agent should be able to handle counterflows from different directions (such as forming parallel lanes) [2] or find the best alternative route to exit the venue (not necessarily the shortest route) [3].

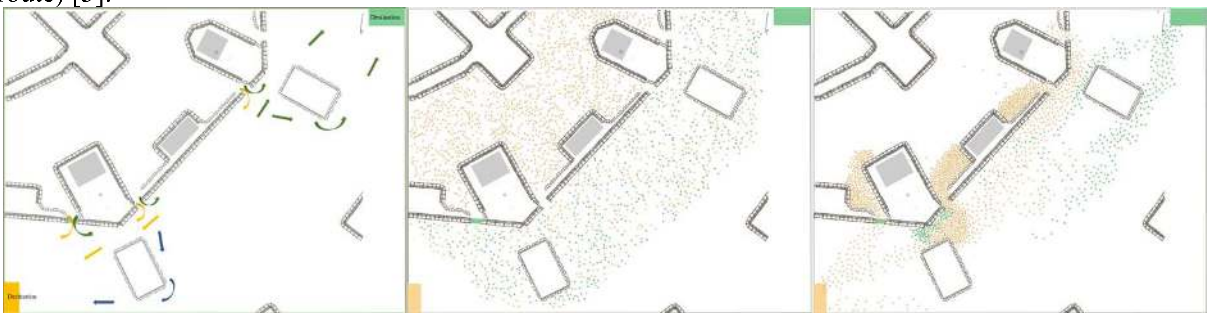

Figure 1: Real-world counterflow scenario (a) Schematic representation of the actual flow routes (in yellow and green arrows) and the desired additional flow routes (blue arrows) (b) at t =0 sec and (c) at t = 30 sec in the *crowd:it* simulator

The proposed model for simulating pedestrian crowd movement involves a continuous cycle of calculating the minimum time to collision between agents, and then acting. It calculates the minimum time to collision between agents and solves for it using a quadratic equation. A penalty function using the agent's preferred velocity, step size and time to collision is introduced to penalize the decision of an agent if it moves away from its goal or comes closer to other agents. The model includes an impatience factor (0 to 1) to handle individual differences among pedestrians. The model has been tested using the agent-based pedestrian simulator based on the Optimal Steps Model (OSM), *crowd:it* [4] and the simulations will be performed for counterflow in small test scenarios such as ISO 20414 Test 6 (counterflow through a small corridor) [5] as well as for real-world scenarios with multidimensional flow where clogging occurs (Fig. 1). The goal is to provide a simple, yet powerful counterflow model for solving counterflow problems in medium-density situations.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Estimating the capacity of railway platforms and stations

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Railway stations and platforms are designed for a lifespan of several decades. Therefore, a proper design of the pedestrian areas is needed. For this, the capacity and the speed-density relation for different facility parts is a key component for a proper design. Still, the values used for station design in Switzerland are mainly based on theoretical derivations and expert knowledge. Nowadays, real-life tracking data from railway stations is available to get a better insight into specific situations [1]. Nevertheless, determining the capacity of different facility elements is challenging, as the design platform density is well beyond the density at capacity, which limits the real-life data at higher density to a few outliers. In addition, the platform is used for boarding and alighting as well as walking and waiting, which results in different densities and profiles depending on the presence of trains [2].

As expressed in the fundamental diagram, the speed-density relation was useful in addressing these issues. For this, the speed-density-flow relation was plotted at different levels ranging from a whole platform section to areas covering only a few square meters. Waiting pedestrians were excluded from the speed calculation but included in the density calculation. Afterwards, the fundamental diagram curve proposed by Weidmann [3] was fitted to the data using different parameter values. Although the data does not reach higher densities, the capacity of each area can be estimated using the fitted curve.

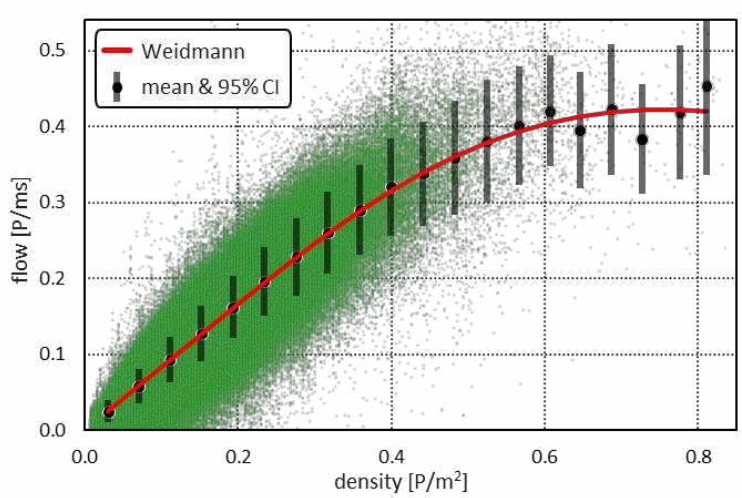

Figure 1: Flow-density measurements for a central platform section and the fitted Weidmann curve [3]

The results show that the flow-density curves show a good fit to the mean of the data. Nevertheless, a large scatter of the individual data points is visible. The derived maximum flow is considerably different depending on the measurement location and the area size and ranges roughly between 0.4 and 1.2 P/ms. It is suspected that due to the less goal-oriented behaviour of boarding passengers before train arrival, the presence of obstacles and waiting pedestrians, and the multidimensional flows in railway stations, the capacity values are generally lower than average values from the literature. Therefore, the specific pedestrian behaviour and characteristics need to be considered for station design.

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PedPy: A Python Toolbox for Pedestrian Dynamics Analysis

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A common approach of pedestrian dynamics research is analyzing trajectory data from field studies, laboratory experiments or simulations. This data can be used to calculate important characteristics such as density, velocity, and flow. To support researchers from various fields, and ensure reproducibility of research results, we have developed a user-friendly framework for this type of analysis called PedPy. This tool builds on the functionality of our previously developed tool *JPSreport* [1], which is widely used for computing Voronoi density, flow, and velocity profiles [2].

However, JPSreport had a drawback in its usability, making it difficult for users to install and process results. PedPy aims to improve upon this by providing a more convenient tool for the same analysis.

With *PedPy* [3] we present a new tool that builds upon the functionality of *JPSreport,* but with a focus on improved usability and reproducibility of results. It is being reimplemented as a Python module, making it easy to install locally as a Python package or to access remotely on a collaboration platform such as Google Colaboratory. In addition, PedPy will be integrated into the JuPedSim-Dashboard, an online interface for analyzing trajectory data. The goal is not only to provide the functionality but also to provide an infrastructure for an easy contribution of own ideas using trajectory data so that newly developed general analysis methods can be shared with the community.

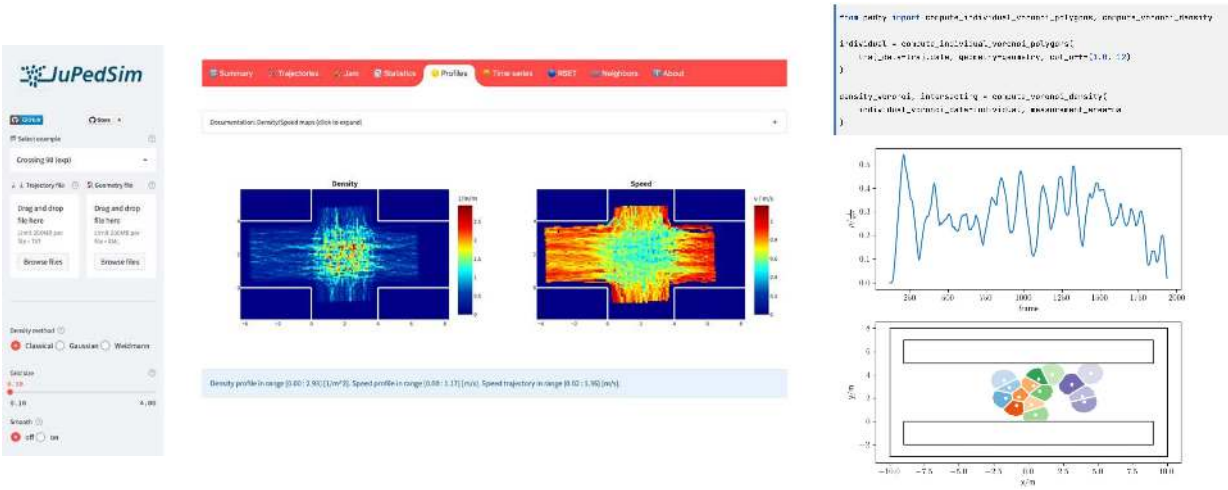

Figure 1: Left: Density and velocity profiles computed with PedPy in the JuPedSim-Dashboard. Right: Exemplary representation of the calculation of the Voronoi density with PedPy.

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Be FAIR to Pedestrian Dynamics Data

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By providing openly accessible data, the possibility to reproduce findings and perform further analyses emerges, increasing the overall scientific rigor. Therefore, we share all our experimental data since 2005 in an open access data archive [1]. However, the data provided is described in varying degrees of detail, with lack of consistent and automatically accessible metadata, and different data structures and formats over time. Thus, to currently reuse data from the data archive, a search process across different resources, like corresponding papers, must be carried out.

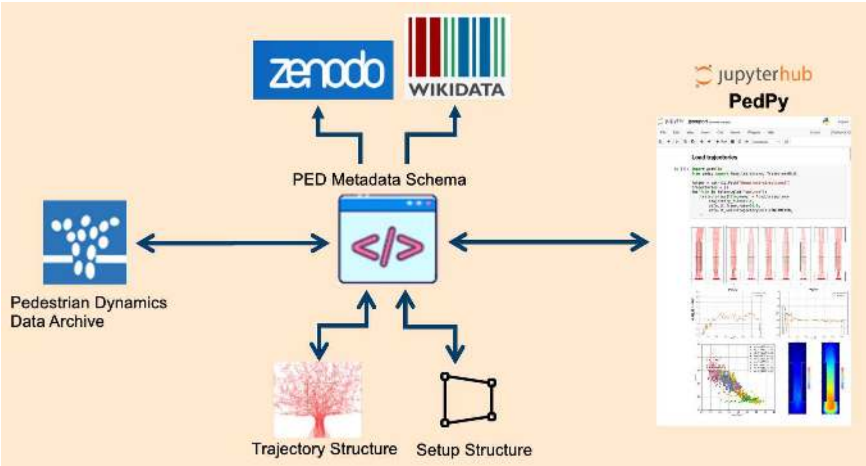

Figure 1: Embedment of the metadata schema of pedestrian dynamics data.

For this reason, we are developing a hierarchical extensible metadata schema to annotate our data with elaborate metadata and are developing standardized data structures with corresponding software libraries for two of our main data sources, the trajectory and the setup data. The embedment of the metadata schema and the connection to the data sources are visualized in Fig. 1. With this step, we make our already open accessible data better findable, interoperable and reusable, for us as well as for our research community, while simultaneously improving the compliance with all FAIR data principles [2]. Furthermore, the developed metadata schema and the standard data structures could help to establish a basis for coherence within our research community.

The metadata information of our controlled experiments can be synchronized to other repositories like WikiData or Zenodo and connect the linked data directly to analysis frameworks like our open source analysis library PedPy [3].

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Social Force Model in Complex Geometries: Access of fans to San Mamés Stadium Using Empirical Data

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The Social Force Model (SFM) [1] is one of the most popular models in pedestrian dynamics. Plenty of authors have studied the dynamics of evacuations using the SFM [2], simulating the exit of pedestrians through one or multiple gates in simple geometries. The definition of pedestrians' desired direction in those simulations is straightforward: a single vector pointing towards the exit is sufficient. In this contribution, we focus on the definition of the desired velocity and the application of the SFM in complex geometries. We simulate the access of fans to San Mamés football stadium in Bilbao, using the data of the entrance rate of fans to the stadium provided by Athletic Club.

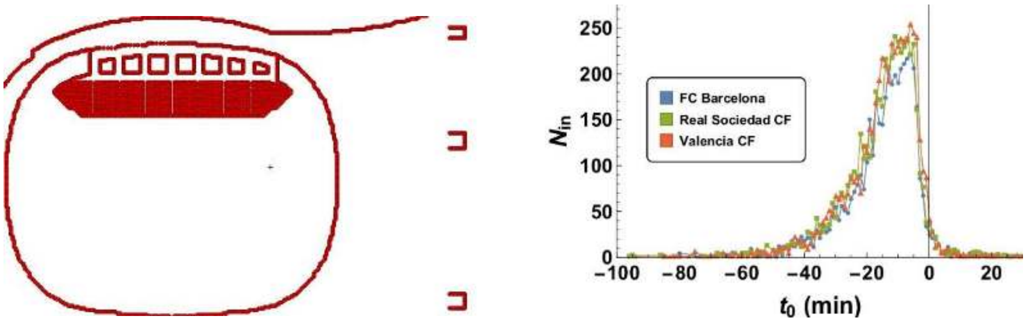

Figure 1: Computational version of the stadium (left), arrival rate of fans in the three selected matches (right).

Using a macroscopically calibrated SFM [3], we simulate the motion of football fans from the streets near the stadium to their seat within the grandstand. Solving Laplace's equation, we create a desired velocity field to induce the motion in the complex geometry of the stadium, shown in Figure 1 (left). We tune the flow of people through the entrance including a "flow control parameter" to reduce people's desired speed when the get close to the turnstiles, and we match numerical arrival rates with the empirical ones in Figure 1 (right). After the calibration of the "flow control parameter", we study the magnitude of the local densities of people that may arise in scenarios prone to create large crowds of people, such as a sudden arrival of a large number of fans in a short period of time, or a match with a 100% of attendance. The local density of people surrounding a given individual is calculated using concepts of the smoothed-particle-hydrodynamics method.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

How to quantify the distribution of pedestrian arrivals?

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Developing reliable models for pedestrian dynamics is key to a vast number of applications aimed at increasing the level of efficiency and safety in urban settings, as well as the level of comfort during our leisure time. The development of reliable models calls for a fundamental understanding of the way pedestrian moves and interact with each other, in crowds and with the environment. For this reason, much attention has been posed in the past on modeling crowds with different approaches and at different lengths and time scales [1]. One issue that has been often overlooked is what is the time distribution between pedestrians in crowds. In an urban facility, like a metro or train station, the inter-arrival times between two successive pedestrians, entering or exiting the station or a train platform, present elements of stochasticity modulated by complex time-dependent patterns. In this contribution, we will present and discuss a statistical framework and observables that can be employed to quantitatively study and understand the temporal distribution of pedestrians within a crowd. As an example, by looking at the probability distribution between two successive pedestrians, one can clearly see (Figure 1) the natural emergence of at least 3 timescales. In this specific case, the shorter time is associated with the inter time between two persons immediately close to each other, the 6-minute timescale is associated with the (average) time between trains on the platform, and the 5 hours interval is associated with the night period during which no train (and thus no pedestrians) were present on the platform. These temporal patterns can be used to provide more reliable input conditions for crowd simulations.

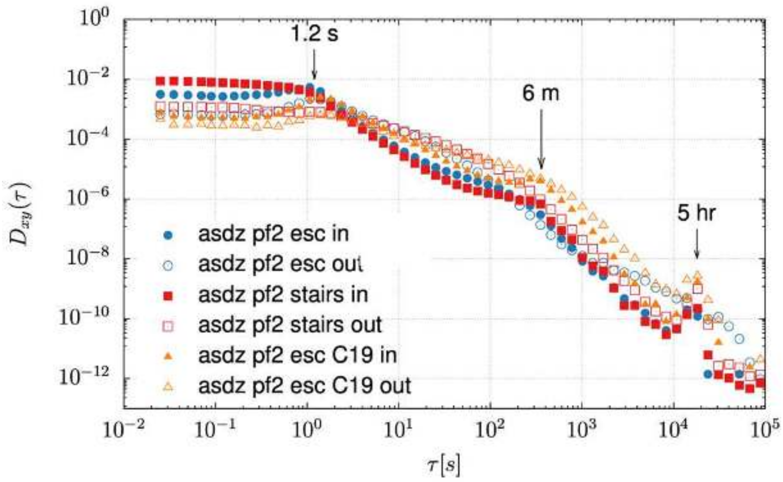

Figure 1: The frequency of occurrence (pdf) of a given time interval, τ, between two pedestrians arriving at various positions on the train platform. Signals from crowds entering or exiting the platform show clear differences but the same typical timescales are visible and are associated with intra-person arrival times, the average time between trains, and the night period without trains.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Route choice decision with an upward/downward arrow on the emergency sign in underground space

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Emergency exit signs with arrows indicates not only the position of the emergency exit but also the direction or route to reach there in an underground station and a basement floor in a building. The recommended standards of graphics and colour on emergency signs are specified by ISO and used worldwide [1]. Among these signs, the upward arrow indicates forward in some countries; otherwise, the downward arrow indicates forward and also down to the lower floor in a staircase. The arrow's guiding direction depends on the region or country's regulation. These upward/downward pictograms can indicate that the stairs leading upward/downward are evacuation routes, respectively. Persons may choose the wrong direction depending on the positional relationship between the sign and stairs; for example, people aim the stair while the sign leads them to the front on the same floor. The placement planning, including the effect of the arrow signs on the escape route choice, is necessary so that the persons accurately follow the route pointed out by the sign. In a previous study [2], the selection of routes connected with squares on the same floor level was examined, however, the selection of routes including different floors was not clarified. This study aims to identify the changes in the escape route choice, as influenced by the arrow direction of sign and the positions of stairs in the escape route, and to clarify the effect of the arrow signs on the route choice based on the aforementioned changes.

We conducted experiments on route choice under the combination of arrow directions, escape route width, and the stairs' positions. Participants of 24 non-disabled candidates with normal vision stood and chose the route at the same position through all trials in the experiment. Each participant tried all parameter combinations. The experimental spaces, where the route choices were carried out, were provided the participants with by walkable VR System through Head Mounted Display (HMV). To represent the actual experiences in VR, the positions of the participants in the experimental space were set to move according to those in the real. Thus, participants can freely watch the VR spaces from various angles according to the movement of their heads. Fig.1 shows the examples of the experimental spaces varied according to the position of stairs and width of the passage.

Fig.1: Example of experimental space

In this presentation, we talk about the variation of the choice of passage or stair under a range of spatial conditions. The results will be helpful and effective in sign planning and the simulation for building evacuation. The Ethics Review Committee of Waseda University approved the study protocol.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Waiting pedestrians at railway platforms: an experimental study

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In public transport facilities, such as railway platforms, passengers spend a significant amount of time waiting. Hence, the distribution of waiting passengers along the platform has a strong influence on the performance of train stations. However, to date pedestrians waiting behaviour and factors that influence the choice of waiting places has only been subject to few studies (cf. Ref [1-3]). The study aims at investigating the effects of platform obstacles and waiting time on the distribution of waiting passengers. In order to analyse these factors unaffected by outer parameters laboratory experiments were performed using a mock-up platform with the size of 7x20 metres. The influence of obstacles was tested using three different setups: a platform a) without obstacle, b) with a narrow obstacle (comparable to an info-board) c) with a wide obstacle (elevator). Each setup was tested with 40 and 100 participants and the waiting time was varied to be either 2 or 4 minutes. After the waiting time the train arrival was announced and movable stairs acted as train doors.

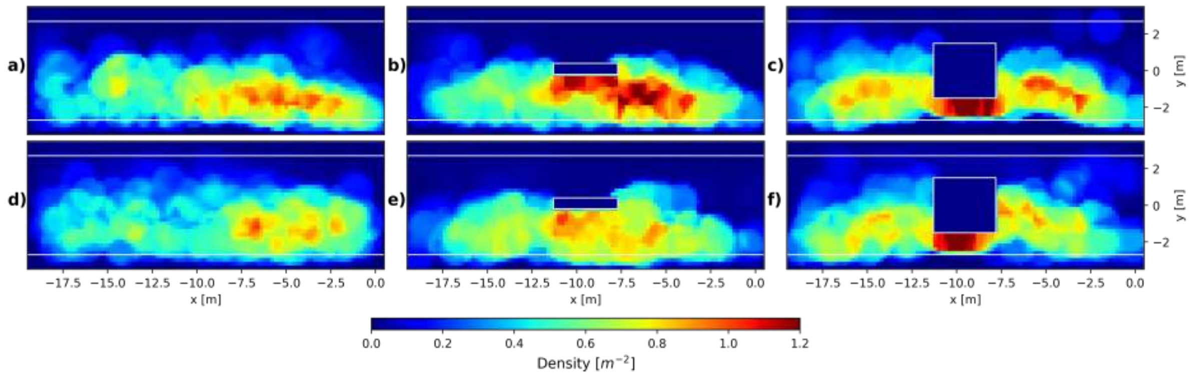

Figure 1: Density profiles for N=40 participants. a)-c) 2 minutes d)-f) 4 minutes waiting time.

Participants were informed about the side of the train arrival and this causes them to mainly wait at the side of the expected train arrival. Density profiles are used to determine preferred waiting places (Fig.1) and factors influencing the choice of waiting places. Based on the density profiles participants are expected to choose their waiting positions as a trade-off between different factors. While short distances to the entrance and the side of train arrival are positive factors, the platform's edges and the area directly in front of the entrance act repulsive. Obstacles have two effects: the side facing towards the expected train arrival is a preferred waiting area, the opposed side, due to the limited line of sight, has a repulsive effect. Following the work from Ref. [4] these factors are transformed into floor fields modelling the space usage by a superposition of attractive or repulsive areas. The results can be used to optimise the pedestrian distribution at railway platforms and act as base for modelling and simulation of waiting passengers.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Research on pedestrian wayfinding behaviour in large public space utilizing non-immersive VR platform

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The expansion of urbanization has led to the construction of a large number of public spaces, such as transportation hubs and commerce, to meet the living needs of urban residents. However, it is not clear how pedestrians' behavioural characteristics in public spaces are affected by the differences in environmental layout, travel purpose, and individual physiological and psychological heterogeneity of pedestrians in terms of walking, wayfinding choices, and other aspects.

Therefore, in this work, a pedestrian wayfinding behaviour experiments is conducted in the built non-immersive virtual reality platform and a pedestrian route choice model that integrates route characteristics, differences in route marking information and pedestrian individual attribute factors is proposed to study the pedestrian wayfinding behaviour in large public spaces. The pedestrians' route choice dataset is based on the non-immersive virtual reality platform we constructed, obtained by participants' walking trajectory data in the scenario of Tianjin West Railway Station and the results of a post-experimental questionnaire. Following this, a hybrid Logit model is developed to estimate the influence of these factors on the pedestrian route decision process, and the utility functions corresponding to different routes are obtained.

The results show that the utility functions have the same predictions for pedestrian wayfinding outcomes as in the validation set, and that route characteristics factors and individual pedestrians' prior familiarity with the scene have a significant effect on route selection. We also found through the experimental results that

(1) The average hesitation time during path selection was 40.35% longer for females than for males, and participants who were familiar with the scenario were able to reduce the average hesitation time during path finding by 18.18%.

(2) On the whole, the crowd prefers to choose the route that can obtain the same character information as the destination when making wayfinding decisions. For example, when the number of the target point is A9, pedestrians will focus their attention on the character 'A' first and look for the location related to 'A', rather than the number '9'.

(3) The average length and width of the routes options chosen by women were slightly higher than those chosen by men, and they tended to choose routes that provided more walking space and therefore might require more walking distance.

Our study concludes that for pedestrians in large public spaces, their wayfinding process is influenced by characteristics such as path length and width, path marking differences, and their familiarity with the scenario. Meanwhile, this research can provide guidance for the optimization of layout structure in public space.

Figure 1: A participant using the Desktop VR during the experiment.

Figure 2: Top view of the virtual reality experiment scenario.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Older Adult Stair and Walking Speeds from Controlled Trials as Inputs into Simulations of Retirement Home

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Given current demographic trends [1], one population of particular interest is older adults as there are known fire safety risks associated with this population [2]. As such, there is a need to revisit the current data sets of walking and stair speeds used in egress analysis with a critical eye to determine whether they are appropriate and representative of current older adults. The objectives of this work are: 1) to add new measured data to the current database of stair movement speeds for the older adult population, 2) to couple these stair movement speeds with recently measured horizontal movement speeds and utilize them as input into a retirement home simulation using two widely used models, 3) to compare the predicted outcomes based on a key input parameter, movement speed, and 4) to compare the predicted outcomes between the two modelling tools.

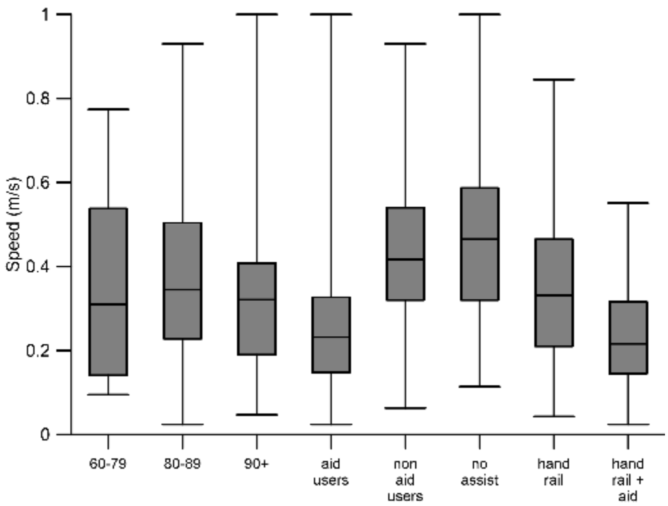

Figure 1: Descending Stair Speeds of Older Adults

Preliminary results of 3-stair descent speeds from controlled trials of older adults residing in a retirement home facility in Ontario, Canada, reveal some important considerations related to egress. Older adults who walk with an aid in daily life descend stairs significantly more slowly than older adults who do not use an aid (mean = 0.26m/s, SD = +/-0.15m/s aid users; mean = 0.42m/s, SD = +0.18m/s non-aid users). Similarly, older adults who descend the stairs in an assisted manner (using handrail, or handrail and their aid) move significantly more slowly than those who are able to descend unassisted (mean = 0.33m/s, SD = +/-0.17m/s assisted descent; mean = 0.48m/s, SD = +/-0.21m/s unassisted descent). It is hypothesized that these significant differences in mean descending speeds in conjunction with the variability in speeds seen across the age range, aid use and whether or not descent is assisted, will have a large impact on predicted egress outcomes when modelled at full-scale. Additionally, these results will contribute to current databases ensuring stair speeds are representative of older adults.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Estimating the congestion at outdoor events from the count of Bluetooth low-energy devices

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Understanding the crowd dynamics with movement has received increasing attention recently from various fields like marketing and crowd management, driven by population growth and the need to control infectious diseases. For example, one of the purposes of an event is to attract a large number of people, but if a large number of people gather in the same place in a disordered manner, it hinders people's movement and creates disadvantages and dangers. Therefore, there is a need to maintain the benefits of gathering people while mitigating risks that can occur because of congestion. For that, we need to grasp the crowd situation more accurately. In recent decades, crowd dynamics have been measured quantitatively in various ways depending on the context. On the other hand, it is necessary to capture behavior on a scale of tens of meters.

In order to examine the method of consistent situation awareness, in this research, we conducted an experiment to install sensors and measured congestion at an event venue that is held in an area of about $3 \times 10^4 m^2$ (3 ha) or more for several days. The sensing system is composed of Raspberry pi and counts the number of Bluetooth low energy (BLE) devices around the sensing system. In general, as the density of people around the sensor increases, it becomes more difficult for signals from distant people to reach them. Therefore, the relationship between signal strength and the number of people around depends on the number of people itself and becomes complicated. To estimate the number of people from the count of BLE devices whose signals with the Received Signal Strength Indicator (RSSI) are above a certain value, we examined the number of people in an area within a certain distance from the sensing system from snapshots (Fig. 1). Furthermore, we investigated the relational expression between the number of people in an area within a certain distance and the distribution of the RSSI that the sensing system had received. Our results indicate that we can estimate the number of people within a certain length of fewer than 20 meters with reasonable accuracy by controlling the RSSI threshold.

Figure 1: State of the target event. We investigated a relational expression that counts the number of people from such a photograph and counts the number of people around from the measured value by the sensor.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Movement strategies when people encounter each other at a bottleneck

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Knowledge of the dynamics of people crossing a bottleneck is of safety importance, since bottlenecks are a key point for pedestrian flows. Individual features such as the body's use of space, especially the rotation of a person's upper body, are becoming increasingly important, as these improve the description of physical interactions and allow space requirements to be described and modelled more realistically.

In order to investigate the dependence of the movement on safety-relevant influencing factors in confined spaces, we performed two series of experiments. In the first series, participants walked through a bottleneck individually and in the second series, participants encountered each other from up to five different starting positions while the encounters consisted of two to four people. Trajectories as well as 3D motion data was recorded for every participant.

We present a study in which space utilisation and the 3D motion of participants within the available space is investigated, by paying special attention to movement strategies like speed evolution, walkway displacements, shoulder rotation and foot placement. This is achieved by comparing data from the encounter experiment with data from individual movement. Already, individual movement shows clear dependencies on, for example, the approaching angle. The aim of the study is to answer the question how the presence of other people changes the movement when walking through a bottleneck.

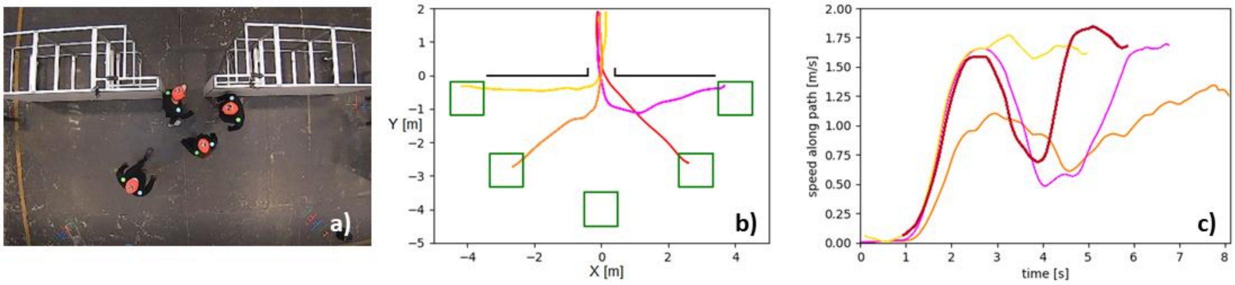

Figure 1: (a) Snapshot of an exemplary run of four people passing a bottleneck. (b) Trajectories and (c) corresponding time-speed diagram for these people. Participants started from designated areas (green squares).

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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The effect of small groups on bicyclists' Riding performance and Gaze Behavior: A comparison experiment

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Cyclists are vulnerable road users. Recent surveys show that cyclists are different from pedestrians and motor vehicles in the motions. To be specific, the bicycle movement not only presents parallel, chasing, gathering and dispersion phenomena like pedestrians, but also has inertia similar to motor vehicles, following road direction and lane restrictions. Therefore, this paper takes the crowd collectiveness into consideration, mainly focuses on the eye tracking characteristics and behavioural decision-making of group cyclists.

In this paper, a comparative experiment is conducted on the urban roads to compare safety behaviours (such as riding stability and steering smoothness) under different riding conditions. It reveals the differences of visual search patterns and behavioural decisions between individual and group cyclists in urban level intersections.

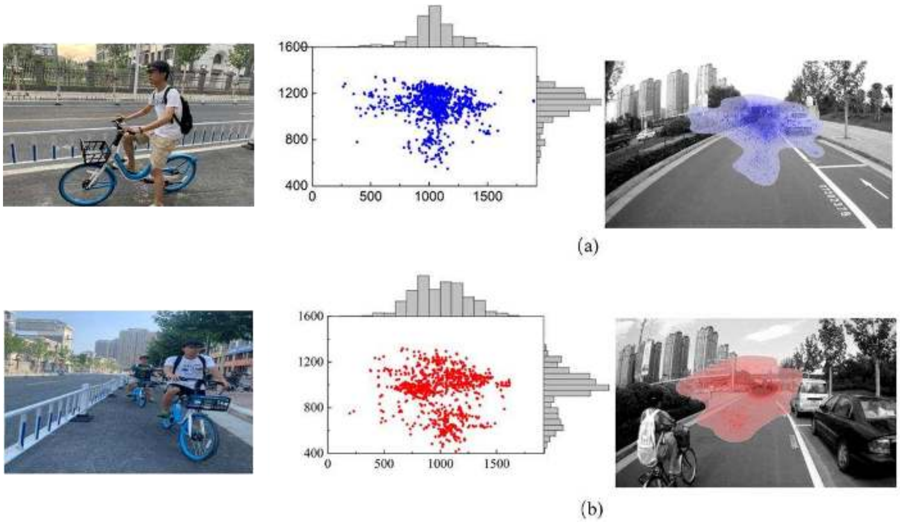

Figure 1: The gaze area distribution of different cyclists. (a) The individual cyclist, (b) the group cyclist.

In the experiment, three typical urban intersection scenarios are selected, and three indicators, the overall gaze area, AOI (area of interest) gaze ratio and first gaze traffic signal distance, are applied to analyse the eye movement characteristics of group and individual cyclists. (1) Compared with the individual, the overall gaze area of the group cyclists is tilted, shifting some attention from the surrounding environment to the location of the nearby companion (as shown in Figure 1), resulting in a correspondingly smaller range of perception of the environment. (2) For the group cyclists, the AOI distribution varies a lot, with 18% attention time on peers. (3) Individuals pay attention to traffic signals earlier than group cyclists, and group cyclists have lower levels of safe attention than individual cyclists. In addition, individual cyclists have a higher lateral offset than groups. The steering entropy of groups is significantly higher than that of individuals, increasing by nearly 20% in complex intersections. Compared to individuals, group cycling speed is reduced by about 16.7%, speed standard deviation is reduced by 33.6%. The influence of the group on the perception and prediction ability of danger in the road traffic environment is revealed.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Mental Simulation of People Movement

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A range of tools are used by practitioners in the design of the built environment to understand and assess how people move within a space, including static calculations and computer simulation software. These tools provide a means to gain insights which can be used to improve operational procedures, architectural layout, or/and informational systems. Underpinning all tools is the expertise and competency of the practitioner to appropriately set-up and interpret produced results. A core part of this is ensuring the practitioner has the ability to imagine how people may or expected to move within a given environment and see if this is consistent with what the results from the tool provide. As part of this process, a practitioner may imagine how people move within an environment or part of an environment in order to develop expectancies for comparing with the tool results through a process of mental simulation. Indeed prior to the use of these tools or on projects which do not require their use, a practitioner may perform such mental simulation (formally or informally) and provide suggestions if a problem is thought to exist in the design or a potential improvement in the people movement system. Mental simulation in this context comprises a practitioner thinking how people may choose to move within an environment, informed by the practitioners past experience, to develop a narrative using a casual chain of events. The process may also be used to derive how people actually moved in past situations e.g. after a crowd crush incident, etc which may be informed by information a practitioner has about the incident, however, the focus of this study is on mental simulation for future people movement which have yet to happen. The term mental simulation is also used in the other domains with different definitions and applications. For example, in sports science it can refer to people imagining doing exercise and achieving the benefits of doing it in order to promoting actually doing the exercise [3]. These alternate definitions in other domains are not within the scope of the current study.

The process of mental simulation involves a practitioner taking information based on past experience of how people move in similar situations, defining an initial set of assumptions regarding a built environment and its population, then abductively inferring how people may move within it in the future. The process may be repeated for considering different conditions/influences for multiple scenarios. Mental simulation of people movement can be used to anticipate potential problems, areas for improvement in a given design, or identifying errors in outputs from associated tools. Despite this, little research has been conducted regarding the extent/credibility a practitioner can mentally simulate people movement with confidence and what factors influence this process (e.g. training, past experience, etc). There is also little guidance of how to mentally simulate people movement to inform the design process within the built environment. This paper will begin to address some of these challenges.

The more relevant experience, knowledge, and expertise a practitioner has for a given built environment type, the increased likelihood of them being able to develop more clearly defined expectancies of how people may move as part of a mental simulation. Similarly, if a practitioner has real-world experience of seeing the same or a similar scenario as the one which is to be mentally simulated, then this can influence expectations (in addition to providing a reference of credibility for the mental simulation process). A practitioner can test and revise these expectancies based on new information (e.g. new alternate viewpoints, informed by results from a tool etc). Assessment of credibility for the mental simulation is of key importance in determining the extent it will inform the design process and how this compares with the expectancies of other stakeholders also involved in the design process. This assessment of mental simulation credibility may consider a range of factors, including [1-2]:

- Plausibility (the elements are believable, likely, and explainable)
- Consistency (the stages of the mental simulation fit in with each other and have low levels of variability)
- Economy (it is not too complex such that it not possible to be envisaged by the practitioner and communicated with key stakeholders in the design process).

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Experimental study on the splitting pattern of complex social pedestrian groups under bottleneck traffic

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Previous studies have focused on the relationship and movement of small social groups (less than 5 people) mostly in free space [1]. The larger groups of 5-7 people, called complex social pedestrian groups, receives rather scant attention. Such complex groups, especially when passing through restricted environments tend to split into smaller subgroups to stay more stable [2]. Therefore, we conducted a laboratory experiment in a funnel-like scene (Fig. 1) to explore the moving process under the splitting.

The bottleneck width W is 0.8m and 1.5m. The complex social group size N is 5,6,7. During the experiment, the participants (roommates chosen from one class) were instructed to walk normally with conversations from the starting line to pass through the ending line. Through video processing analysis, both small subgroup and individual behaviors are observed. The stable subgroup forms of dyads (mostly in W=0.8m) and triads (mostly in W=1.5m) are still existed, and the subgroup members show minor velocity change and more compact size (Fig. 2(a)-(b)) than the free space conditions [3]. The other pedestrians behave like individuals, that they change the rhythm of walking side by side in response to the narrowing space. When the location offset between the adjacent members reaches a certain level, a split state occurs. There are significant differences among different N but no differences between different W in split locations. The distributions of split locations fit well with double peak functions (R^2>0.99), which reveals the interactions of complex social groups are distinct between free and restricted spaces(Fig. 2(c)).

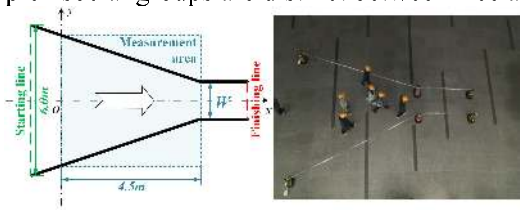

Figure 1: Sketch of the experiment site.

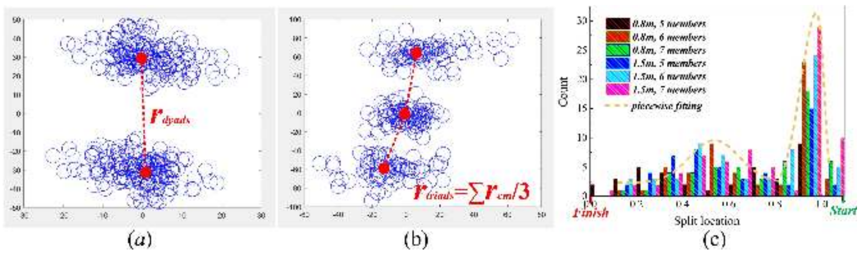

Figure 2: (a) Dyads stable form. r_{dyads} is the distance of dyads. (b) Triads stable form. r_{triads} is the size of triads (i.e. mean distance from the mass centre of each pedestrian). (c)The split locations distribution of different W and N. Dotted line is the fitting of N=6.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Can we study walking velocity using Virtual Reality experiments?

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Pedestrian movement dynamics and choice behaviour has been studied for various decades by means of experiments. First using camera-based technologies, such as time lapse photography and camera recordings, experiments in which researchers followed pedestrians around and questionnaires. More recently, new sensing techniques, such as Wi-Fi, RFID, GPS and depth sensing have been added to the set of research tools. Also Extended Reality systems, such as Virtual Reality and Augmented Reality, are up and coming in traffic research. In contrast to other research methodologies, XR systems allow researchers to study pedestrian behaviour in more complex, and potentially dangerous, environments with a high degree of experimental control. XR systems open up exiting new research avenues. Consequently, more and more frequently XR systems, especially VR systems, are adopted to study pedestrian behaviours usch as wayfinding, route choice and movement dynamics.

While interesting VR results have been presented, the validity of VR systems for pedestrian research can still be questioned. To the authors' knowledge, most validation studies feature the use of VR to study vehicle-pedestrian interactions (e.g. [1] and [2]). Recently, [3] has presented a first step in the validation of VR systems for pedestrian walking behaviour, featuring an unique experiment to validate of pedestrian wayfinding strategies and route choice behaviour in a multi-storey building. Yet, studies that research to what extend the behaviours of pedestrians in VR are similar to the behaviours of pedestrians in real-life settings are still very essential. In particular, studies that validate operational walking dynamics, pedestrian-pedestrian interactions and gazing behaviour.

This study presents a validation experiment that studies the validity of results unravelled by means VR systems for one of these behaviours. In particular, we determine to what extent Virtual Reality experiments can be used to study changes in the free-flow walking velocity of pedestrians. In particular, this experiment features two parts; a Virtual Reality experiment, and a laboratory experiment. All participants take part in both experiments shortly after each otehr. During both the VR and laboratory experiment, participants perform exactly the same set of walking assignments where we vary the illumination brightness conditions in the room. The order of the VR and field experiment are randomly assigned to the participants.

In the VR experiment the participant is immersed in a virtual environment resembling the real-life laboratory environment. A HTC Vive Pro with a wireless adapter is adopted, which allows participants to move through the VR environment using their natural locomotion behaviour. During the two parts of the experiment, we capture the participant's step frequency, body rotation, gazing behaviour, and walking dynamics.

At the PED conference the comparison of walking behaviour of participants in both experiments is presented.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Review on emergency evacuation experiments under limited visibility

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In recent years, evacuation with limited visibility has become a new topic of pedestrian dynamics, which is often explored through laboratory crowd experiments. In order to design and evacuation strategies for ship safety, it is essential to understand the behavior rules of evacuees under low visibility conditions. This paper reviews the relevant literature on evacuation under low visibility conditions in recent years. [1, 2]The purpose is to:

(1) summarize the experimental methods of evacuation under low visibility conditions;

(2) The evacuation time and pedestrian movement speed that affect low visibility evacuation are studied.

(3) The movement mode and typical behavior of personnel evacuation under low visibility conditions are studied.

The connection between pedestrian evacuation experiment and simulation model under low visibility conditions and the complementary relationship between various experimental methods in this field are introduced. Relevant literature shows that the relevant research on limited visibility is still at the qualitative level, and the main difficulty lies in quantitative data collection, such as personnel fatigue, group impact and other information. Future research should focus on quantitative evacuation behavior research, and psychological factors of personnel, such as team guidance, phototaxis, and panic, deserve further study.

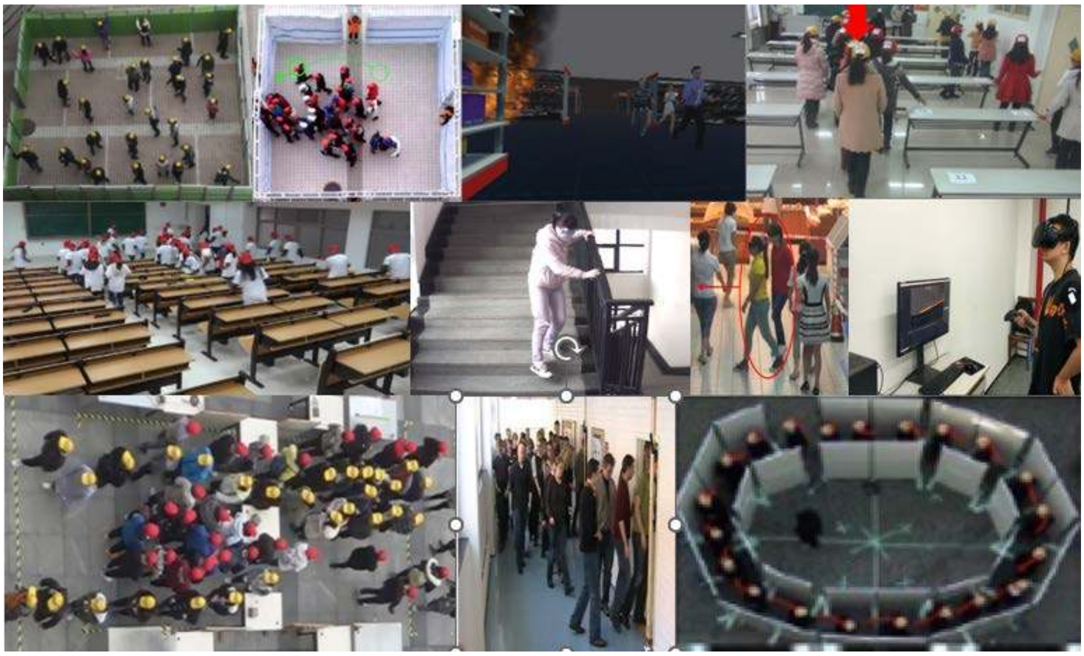

Figure 1: Some experimental scenarios

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Impact analysis of the crowd management approach at Amsterdam Bijlmer-ArenA station

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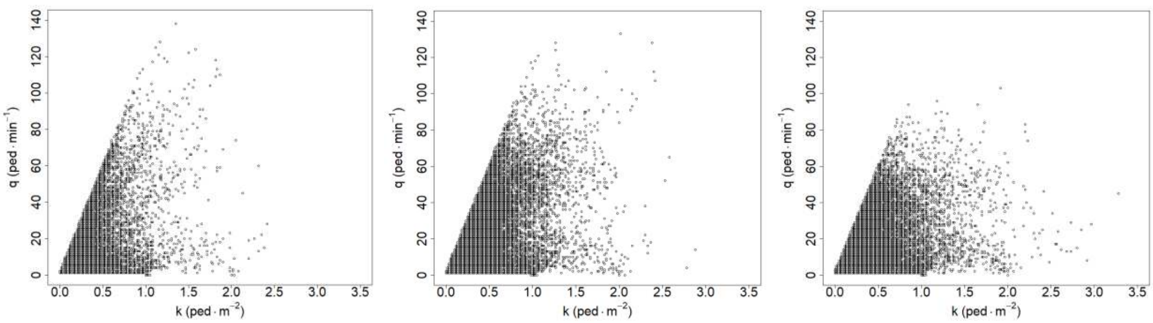
This research presents an impact analysis of a crowd management approach on the safety and capacity of the Amsterdam Bijlmer-ArenA station in the Netherlands, using trajectory data.

Amsterdam Bijlmer-ArenA station is located in an area with three major event locations with a capacity of 71,000, 17,000 and 6,000 visitors. When multiple events end simultaneously, an exceptionally high demand arises at the station. Without intervention, demand exceeds capacity and the safety of the station is compromised. For this reason, (safety) measures are taken on busy days. The crowd management approach adopted on these days consists of special crowd barriers to control the demand into the station, and signage systems to direct people to the entrance closest to their platform.

Currently there is no objective insight into the impact of these measures on the movement dynamics in the station. Objective insight into the effect (size) of the measures on crowd dynamics supports crowd managers in their decision-making. Do the costs outweigh the effect size? What is needed to improve the set of measures? Is a different strategy necessary or more effective?

The aim of this research is to gain objective insight into the effectiveness of the applied crowd management approach. To this end, we study and evaluate the effect(s) of the measures on the crowd dynamics at the station; in particular the effect on 1) the handling of the passenger flow and 2) the degree of crowding in the station hall. The two main research challenges are 1) understanding and quantifying the relationship between the measures and crowd dynamics, and 2) accurately determining the impact of these measures on crowd dynamics given the wide variability in station conditions.

We compare the pedestrian dynamics in the station on days with and without the application of measures. We do this by means of the Macroscopic Fundamental Diagram (MFD). For this purpose, we collected trajectory data at four locations in the station hall using overhead sensors, covering the area around the check-in gates to the eight platforms and partially covering the rest of the station hall, including the entrances. The data is collected over a period of 272 days between May 29, 2019 and March 12, 2020 (i.e., pre-COVID period), featuring 150 days with no events (scenario 0), 99 days with small events (scenario 1), 12 days with large events and without the application of measures (scenario 2), and 11 days with large events and with the application measures (scenario 3). In particular, we study 1) the relationship between density and intensity per 1 m^2 cell per minute, and 2) the relationship between the density of the whole area and the production from the area to the platform per minute (i.e., the flux through the check-in gates). See Fig. 1. for three MFDs at one sensor location over three days, each in different scenarios. We will share the final results at the conference.



a) b) c)

Figure 1: The relationship between density (k) and intensity (q) per 1 m^2 cell per minute at one sensor location for one day in a) scenario 1, b) scenario 2, and c) scenario 3.

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A novel variable-goal approach as universal for pedestrian dynamics in any situation

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In India, as the population grows, the stress on the existing public infrastructure increases. Thus, there is a need to shift the design principles of public spaces from heuristics and experience to a more fundamental approach. Towards, this, several researchers in the past have studied pedestrian dynamics in a variety of scenarios. These include different complex phenomena like lane formation, bottleneck, and evacuation. These investigations have led to forming of several models of pedestrian dynamics with varying degrees of success. Some of these (the social force-based ones) consider a pedestrian as an inertial particle that experiences forces and responds accordingly. However, such physics-based models often lack the aspect of human intelligence and perform poorly in very common scenarios, as we show in this talk. To overcome such limitations, in this study, we propose a novel "variable-goal" approach to mimic the role of human intelligence. While doing so, we show how the social forces can be retained (by a recently developed universal power law model (UPL) [1]) or can even be neglected while retaining accuracy (relative to experiments).

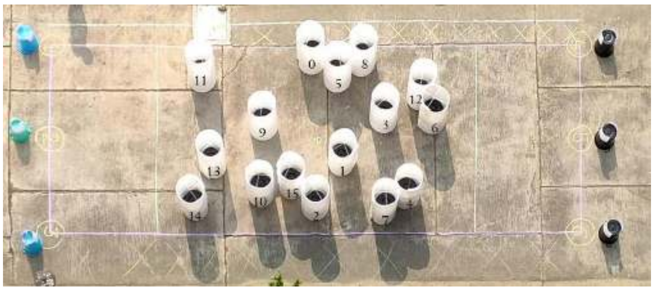
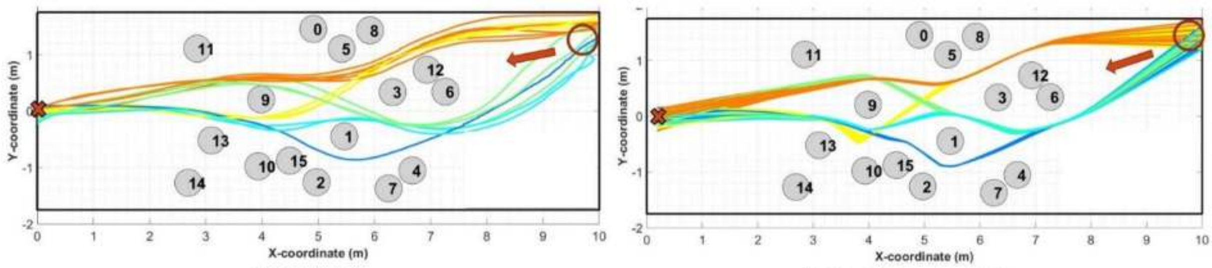


Figure 1: Experimental setup for studying the motion of a single pedestrian through multiple, randomly placed obstacles.

Figure 2: a) Different paths chosen by volunteers during the experiment. b) VGA able to mimic almost all paths for a particular initial and final position.



a) experiment　　b) Simulation using VGA

In addition to the model, we will also discuss our experimental set-up and results, which include head-on walking and dynamics through a maze of obstacles with varying area fractions. We will show in detail how the several weaknesses of the social force-based models are eliminated in our variable-goal approach (VGA), which is consistent with all these experiments [2]. The application of the VGA to common multi-pedestrian scenarios like lane formation and bottleneck will also be discussed.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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The Effective Capacity of Escalators at Railway Stations

Lee Verhoeff
ProRail

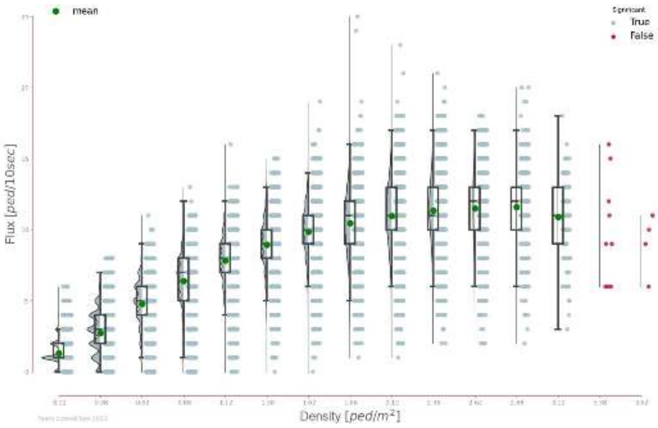

Figure 1: Fundamental diagram as measured directly before the escalators

Researchers such as Kahali and Rastogi [1] cite a theoretical capacity of 11,700 ped/hour for escalators with a nominal speed of 0,65 m/s as stated in the EN115-1-2017 standard and the practical transport capacity as stated by ThyssenKrupp Escalators Americas [2] of 8650 ped/hour. Both values are significantly higher than 4680 ped/hour, the capacity of the escalators at Amsterdam Central Station if these were loaded for a full hour at the measured 75th percentile capacity at peak flux.

The exact process of the missing step phenonomen as reported by Fruin [3] does not appear to have been the focus of significant study in the literature. Explanations likely include the desire by pedestrians to maintain a minimum distance to others and a need to judge the exact movement of the escalator as a prerequisite to safely boarding the same escalator.

The area of a body ellipse as proposed by Fruin but adjusted to achieve Hall's intimate space [4] between pedestrians in the direction of movement has an area of 0,44 m^2; this value is similar to the area of 1 step of a typical escalator: 0,42 m^2. This is in line with the observation that on escalators with only standing pedestrians the average use typically does not exceed 1 pedestrian per step. The capacity of an escalator with an operating speed of 0,65 m/s with 1 pedestrian per step is 98 ped/min. In Figure 1 the flux of 17 pedestrians per 10 seconds (or 102 ped/min) is seldom exceeded.

It appears that the space per passenger immediately before the first moving step limits the number of passengers that can board the escalator in a given period of time. The maximum mean flux in Figure 1 is achieved at a density of 2,88 ped/m^2 directly before the escalator. This density translates to 0,36 m^2/ped and is only slightly less than the area of 1 step or the enlarged body ellipse.

This paper will investigate aspects of pedestrian use of escalators: the queue before the escalator, the process of stepping onto the escalator, movement while on the escalator and the exiting process. This paper will make use data available from sensors at a few busy stations in The Netherlands and will suggest explanations for the observed behaviour of pedestrians.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Critical area prediction in train stations using deep learning

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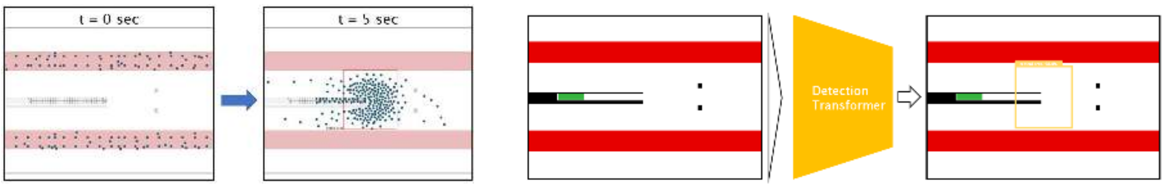
With continuously rising numbers of railway passengers in Germany [1] and Europe [2] in pre-pandemic years, train stations must be able to sustain high passenger capacities in the future. Thus, it is critical to consider crowd dynamics in train stations to prevent dangerous situations such as overcrowding near the tracks or escape exits. This needs to be done particularly during the early design phases, when changes in the planning and layout can still be conducted cost- and time-efficiently [3].

To this end, we investigate high-density scenarios, and identify and quantify bottlenecks such as stairs, escalators, elevators and other narrow passages on the platform. For our data-driven approach, we generate a synthetic dataset of train station floorplans and the corresponding high-density areas. The floorplans are derived from an IFC-based parametric model, and used as input to the microscopic, agent-based pedestrian simulator *crowd:it* [4]. By running various simulations from different initial crowd configurations, the simulator identifies all critical areas by setting a pre-defined, upper velocity threshold. Thus, areas with low-velocity agents are defined as critical (see figure 1(a)) in accordance with DIN 18009-2 [5], which standardizes congestion analysis based on pedestrian velocities.

As a next step we employ an object detection algorithm based on the DETR architecture [6], which is trained and evaluated on the aforementioned synthetic dataset. Specifically, we convert the floorplans into RGB images, and aim to predict the critical areas in those images as bounding boxes, which comprise congested areas (see figure 1(b)). The evaluation will take place with a series of initial pedestrian simulation parameters. This enables a fast assessment of possible bottlenecks and thus provides an early estimate in early design phases.



(a) (b)

Figure 1: (a) Pedestrian configuration at initialization and after five seconds. The pedestrian simulator *crowd:it* automatically detects congested areas based on low velocities (rectangle in red). (b) Setup of the object detection algorithm: The DETR [6] takes the preprocessed floorplan images as inputs, and detects critical areas as bounding boxes.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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The evaluation of data fitting approaches for speed/flow density relationships

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Many experiments in the field of pedestrian and evacuation dynamics focus on the relationship between three key variables: speed, flow and density. These relationships are useful for characterising the dynamics of traffic systems, modelling applications (e.g., macroscopic modelling), and validation [1]. This work provides guidelines to select and analyse data from observations and experiments. The data selection process is linked to some key issues, such as collection methods, measurement uncertainty, and assumptions adopted in the data treatment. In other words, inclusion/exclusion criteria can have a strong effect on the final dataset obtained. This work reviews different methods of formalising the relationships between speed, flow and density, considering the type of data. This paper also expands on the discussion on common mistakes in the statistical analysis of pedestrian movement data from [2]. First, traditional statistical methods (e.g., curve fitting and rolling average) are reviewed and analysed, for the specific case of speed/flow-density relationships. Second, the benefits and drawbacks of common machine learning regressions are explored (e.g., kernel smoothing, gaussian regression, support vector machines). This paper is not meant to provide the optimal approach for each possible dataset. It presents a comprehensive review of existing approaches and guidelines on how to apply them to real datasets from pedestrian, evacuation, and traffic dynamics, often varying in size, distribution, and homogeneity (see Figure 1). In conclusion, this work represents an attempt to facilitate the work that pedestrian and traffic researchers do when analysing speed, flow and density datasets and is deemed to stimulate a discussion on this topic within the Pedestrian and Evacuation Dynamics community.

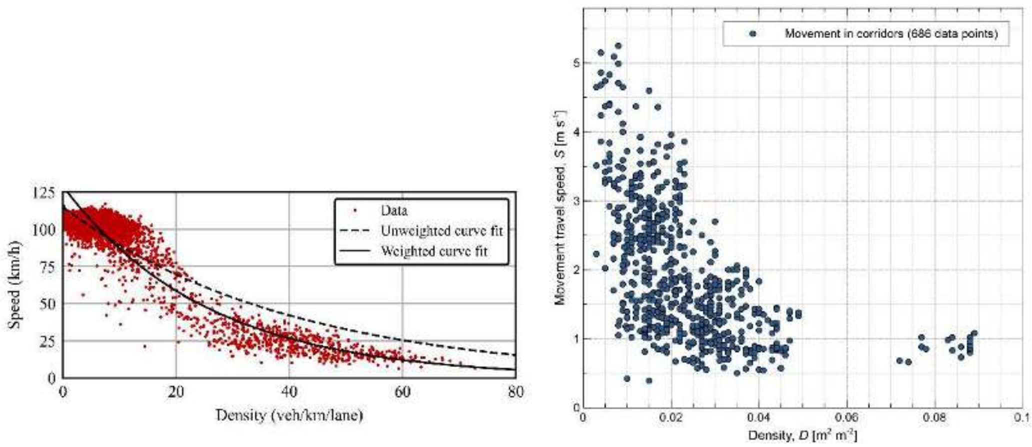

Figure 1. Two different optimisation schemes to fit traffic evacuation curves to data from the 2019 Kincade fire (left) [2] and an example of an imbalanced dataset concerning pedestrian movement of children [3].

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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METHODOLOGY FOR ESTIMATING ESCALATOR CAPACITY: A CASE STUDY OF DELHI METRO RAIL STATIONS

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Escalators are the common types of facilities used in various types of infrastructure such as public transport terminals, shopping malls, sports arenas etc. to transport pedestrians from one level to other. Understanding escalator and pedestrian characteristics is crucial in estimating the capacity of escalator in normal conditions as the evacuation of pedestrians depends on them. Some recent studies show the comparison of the theoretical and actual capacities to help upgrade the facility [1]. The influencing parameters such as width, slope and speed that affect the escalator capacity and the underlying fundamental diagrams are reviewed here [2]. Further, the available standards and guidelines show large deviations between theoretical and practical capacity values. Also, a wide variation among practical capacity values is observed for the escalators having similar speed. In this regard, a new methodology is proposed to estimate density and hence the accurate capacity of escalator. Figure 1 shows the escalator in operation at one of the Delhi metro stations. Video recordings collected from surveillance cameras of four escalators of Delhi metro rail stations are processed through a MATLAB® based video image processing tool to extract the relevant data. This study proposes a range of values for capacity considering average and maximum densities as the capacity varies when the pedestrian flow consists of different type of pedestrians according to their age, gender and amount of luggage carrying. It is anticipated that the methodology proposed in this paper helps metro rail agencies in estimating the near realistic capacities of escalators under varying operational conditions.

Figure 1 Escalator in operation at a Delhi metro station

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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A force-based evacuation model with context effect on exit choice behavior

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Exit choice is essential for pedestrians' safety during building evacuations. Numerous studies have investigated how environmental factors, social interactions, and individuals' internal factors affect exit choice behavior. The major factors governing the exit choice of an evacuee are the distance from the evacuee to each of the exits and the crowdedness of the exits [1]. The probability of the evacuee choosing an exit with high crowdedness but a short distance may be the same as that of the evacuee choosing another exit with low crowdedness but a long distance. However, when there are three or more exits, the choice is governed not only by the major factors but also by the visual context of the exits. This is due to the cognitive psychological phenomenon of context effects (i.e., preference reversals depending on what options are available), which comprises three major effects: the compromise effect, the similarity effect, and the attraction effect [2]. For example, consider three exit choice sets (Fig.1 (a), (b), and (c)) of Exit A, B, and C in which the attributes of Exit A and C are the same, and the attribute of Exit B is different in the three choice sets. Due to the context effect, evacuees have different choices. Most people will choose the compromise option, i.e., Exit B in Fig. 1 (a), the dissimilar option, i.e., Exit C in Fig. 1 (b), and the superior option, i.e., Exit A in Fig. 1 (c) due to the compromise effect, similarity effect, and attraction effect, respectively.

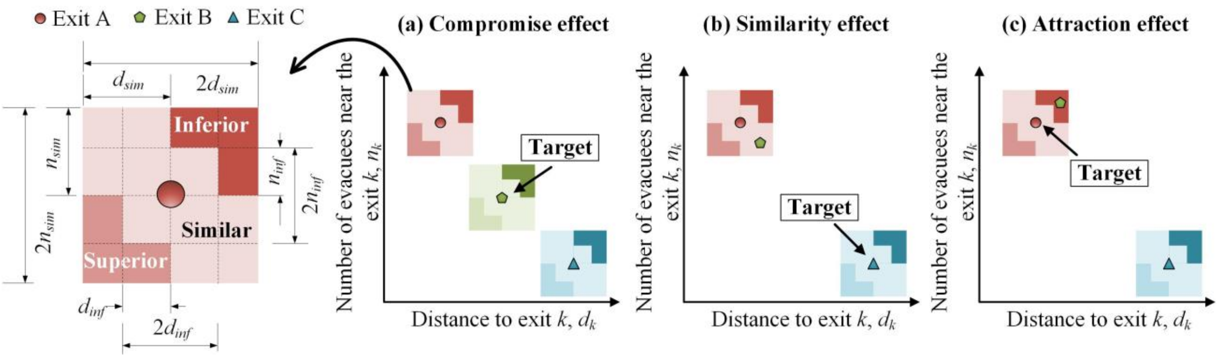

Figure 1: Demonstration of the context effect: (a) compromise effect; (a) similarity effect; (a) attraction effect on exit choice behavior. Three exits with the highest expected preference in a room with multiple exits, i.e., Exit A, B, and C, are proposed to be targeted by comparing with the two attributes of exit, namely n_k, and d_k. Two pairs of threshold values for attributes, i.e. n_{sim}, d_{sim} and d_{inf}, n_{inf} are defined to demarcate similarity and inferiority to mimic the evacuees' psychological responses to the visual context.

Researchers have long known that context effects play an important role in human decision-making. However, to the best of our knowledge, no study has considered these effects in building evacuation. To fill this gap, we implemented the context effect in a force-based exit choice model, i.e., CEEC. Context effects are considered for each evacuee at each time step, and each evacuee made their exit choice based on their visual context. Each evacuee's chosen exit is considered a strong attractive force driving the movement of that evacuee. The performance of the CEEC model was compared with the basic exit preference model, i.e., EP, in terms of their ability to replicate the experimentally observed exit choice behavior. The results show that CEEC outperformed EP at the evacuation trajectories and exit utilities.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Evolutionary stability of social interaction rules in collective decision-making

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Social information provides individuals with indirect information about their environment that can lead to optimised decision-making. In environments with high levels of uncertainty, indirect information is at the same time more crucial and more unreliable. For this reason, individuals must balance the private information they receive from their own sensory cues with the social information provided by observing what others have chosen. These two cues can be integrated using decision making rules, which specify the probability to select one or other options based on the quality and quantity of social and non-social information.

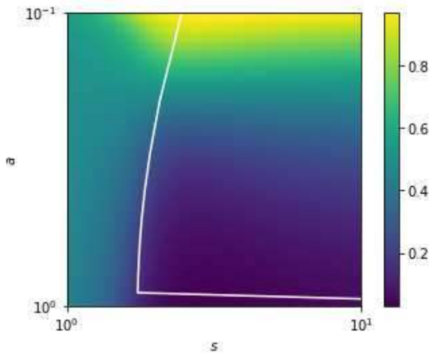

Figure 1: Figure demonstrating the effect of environmental uncertainty (parameter a) and sociality (parameter s) on the group's collective performance. The white curve indicates how the collectively optimal level of sociality changes as the environmental uncertainty increases.

Previous empirical work has investigated which decision making rules can replicate the observable features of collective decision making, while other theoretical research has derived forms for decision making rules based on normative assumptions about how rational agents should respond to the available information. In our recent work [1], we explored the performance and accuracy of one commonly used decision-making rule [2, 3].

We show that two parameters of this model (representing the environmental uncertainty and the agent's sociality) obey necessary relationships under the assumption that animals are evolutionarily optimised to their environment. We investigate under what conditions the collectively optimal and evolutionary stable behaviour occur, and show that over-reliance on social information is sub-optimal for any degree of uncertainty. We further investigate whether this decision-making model is appropriate to all animal groups by testing its evolutionary stability to invasion by alternative strategies that use social information differently, and show that the likely evolutionary equilibrium of these strategies depends sensitively on the precise nature of group identity among the wider population of animals it is embedded within.

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Calibration of Decision-Based Crowd-Behaviour Model

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Different methods of calibration are used according to the type of the model, its following application and preferences. Nevertheless, there is no universally right method to calibrate the model. In the last decades, statistical methods used for calibration became more popular [1]. Although advanced methods can be applied, the maximum likelihood estimation bringing the point estimate of a model parameter is mostly used. However, the statistical methods are promising.

Our developed model is based on agents' decisions. Here, we focus on the operational phase covering the crowd behaviour; details about the model can be found in [3]. The main parameters influencing the dense-crowd behaviour are pedestrian size, the field of vision $\nu \in \langle 0, 2\pi \rangle$, crisis acceleration $a_{\text{crisis}} > a > 0$, where a represents standard (non-crisis) acceleration, and maximum possible change of pedestrian course $\varphi \in \langle 0, 2\pi \rangle$. The concept of pedestrian sizes was shown very important to capture the density at the exit area properly, see [3]. Nevertheless, the field of vision, the acceleration and the change of pedestrian course are crucial features to prevent the model from being stuck, i.e. they control bridge (arc) appearance. Their significant impact on the outflow is illustrated in Figure 1.

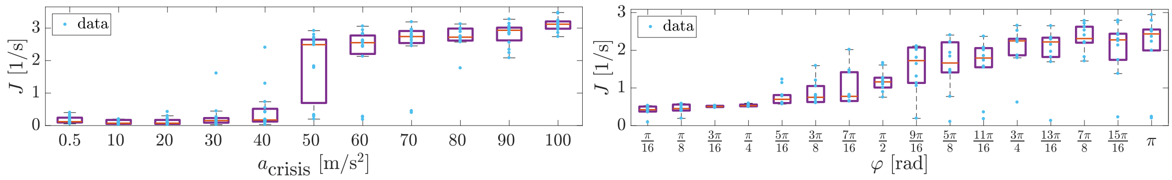

Figure 1: The influence of the essential crowd-behaviour parameters on outflow.

Having developed the decision-based model, the calibration process can be started. Our calibration concept consists of separate calibration episodes to avoid choosing only a few metrics to describe the whole, complex system and rising problems with finding the global optimum. Besides, we avoid high computational time depending exponentially on the number of parameters. Thus, we design separate calibration episodes covering one type of pedestrian behaviour captured by model parameter(s). Then calibration quantities need to be defined (and influenced only by appropriate model parameters); there are the average time length and the number of observed bridges and the outflow for the current purpose.

The crucial part of the calibration episode is its set-up, which will be discussed in detail. The estimate of needed time to get stationary values of calibration quantities will save a lot of simulation time, and the number of iterations estimated by Chebyshev's inequality has a strong impact on the quality of the result. Furthermore, hypothesis testing will be used to find an optimum parametric set, specifically James' test for testing multivariate mean values equality with unknown covariance matrices.

The used scenario is set following the used egress experiment [2], including random inflow set-up as 1.5 ped/s. Pedestrians (undergraduate students) randomly entered the room by one of three entrances, walked to the opposite wall and left the room by one exit. By controlling the input flow, different conditions from free flow to congestion in the exit area were achieved. In total, our sample is made up of 2000 trajectories through 10 experimental runs.

In summary, the calibration of any model is a crucial part of pedestrian movement prediction. This contribution deals with an author's microscopic decision-based model and a general calibration concept that is applied to the phase of congestion. One of the goals is to document the whole calibration process and made it rigorously using mathematical methods, including hypothesis testing. This calibration process could be widely used for any microscopic pedestrian model.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Estimation of Pedestrian Origin-Destination Flow Based on Gravity Model

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Pedestrian origin-destination (OD) flow, which describes where pedestrians come from and where they are heading, is important information for pedestrian management. For instance, when an area is crowded and it is necessary to guide some pedestrians away, OD information can help decide the optimal targets to guide. Nevertheless, research on the estimation of real pedestrian OD is still rare due to the difficulty to collect data, especially in multi-directional scenarios where even manual counting is impossible. Therefore, unnecessary data should be distinguished from the necessary data to save costs. Here, we apply the gravity model to estimate pedestrian OD flow. Although the gravity model is usually used to predict large-scale network flows, such as urban development, and information dissemination [1], we surprisingly find it is still available for microscopic pedestrian flow networks. Afterward, we (A) explore the necessary data when estimating the OD of different pedestrian networks by numerical simulations, and (B) examine the performance of OD estimation using real pedestrian data at a region with pedestrians from six directions.

(A) Numerical simulation to distinguish the necessary data. When applying the gravity model on a network, besides the pedestrian flow at nodes, it is believed that the flows at links among neighboring nodes can improve the estimation accuracy. Nevertheless, in the case of pedestrians, the link flow is costly and difficult to collect. Here, through numerical simulation, we find that the necessity of link flows depends on the diversity of the node/link flows. For example, as shown in Fig. 1 which gives three networks following the gravity model, the flows are even in Fig. 1 (a), diversified in Fig. 1 (b), and highly diversified in Fig. 1(c). The corresponding results are in Fig. 2, where the horizontal indicates the noises of the data and the vertical axis indicates the prediction error. Results show that when the network is highly diversified, there are no merits to collecting the costly link flows.

(B) OD estimation with real noised data. Based on the pedestrian data at a six-directional walking area (30 m×30 m) at a subway station, we find that the gravity model could reproduce the OD at a high accuracy. Furthermore, this accuracy can be reached with only node flows.

Definitions of noises, prediction errors, as well as the results of a wide range of numerical simulations, and details on the OD estimation with noised data will be introduced in the full paper. We believe this research could provide practical and reliable methods to estimate pedestrian OD.

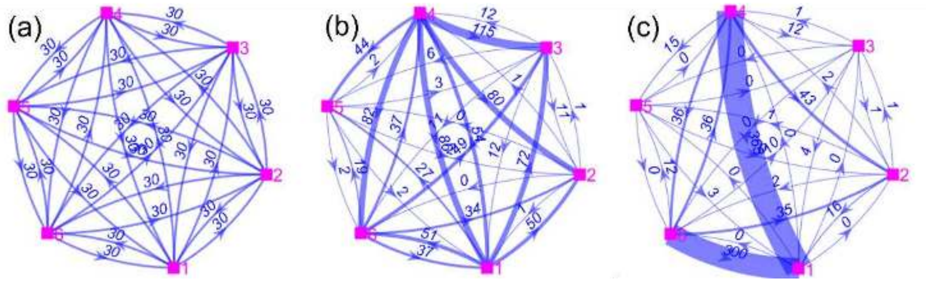

Figure 1. Example of three networks that follows the gravity model with different diversities of node/link flows.

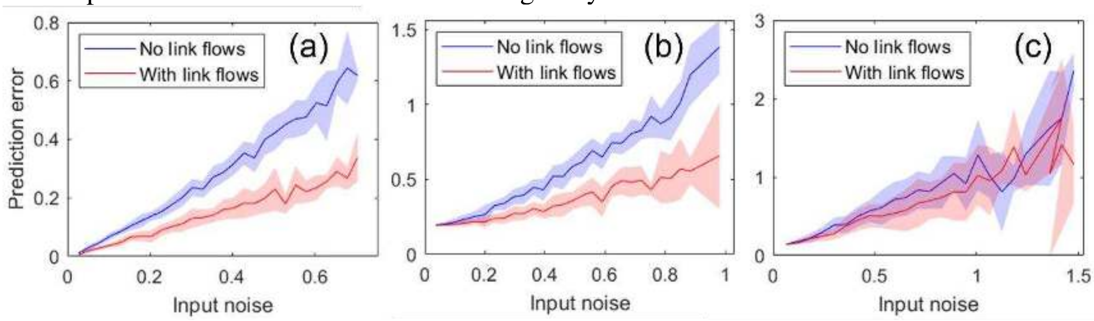

Figure 2. Influence of data noise on estimation accuracy: comparison of using link and node flows.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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How fast is my model? Methods to define the computational complexity of pedestrian models

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To assess how well different pedestrian models can be applied in various contexts two model properties are of great importance. Namely, the validity and the computational complexity. Both are important, as a fast model that cannot provide accurate results is as useless as an accurate model that cannot provide the results in time. Multiple frameworks exist that modellers and model users can use to assess the validity of a pedestrian model. However, there is not yet a framework to systematically assess the computational complexity of pedestrian models. This means, we currently lack the tools to assess one of the two important model properties.

To fill this gap, we present a complexity framework that allows users to systematically assess the complexity of their pedestrian model. Figure 1 shows the basic elements of the framework. The framework describes how to select and apply different complexity methods to obtain a description of the model complexities given the insights you require. In addition, the framework provides a methodology to select and create the test cases.

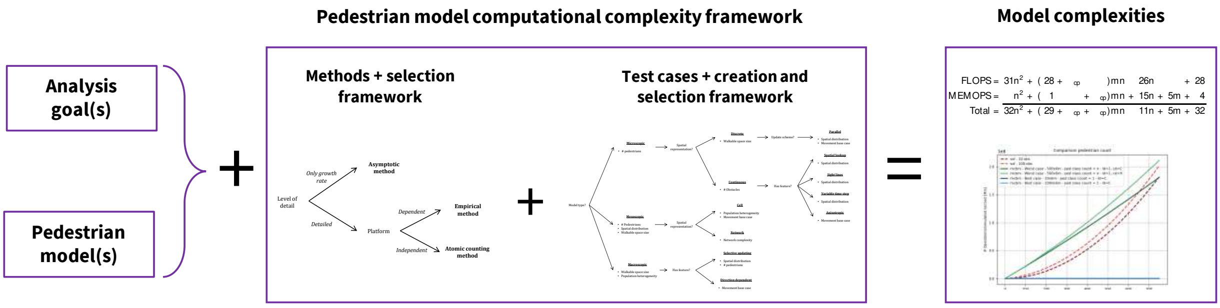

Figure 1: The framework to systematically assess the computational complexity of pedestrian models

The framework features three methods, the asymptotic complexity method, the atomic operations counting method, and the empirical method. Each of these methods has its own strengths and weaknesses. Depending on the level of detail and type of insight a user is interested in, the framework guides a user to the right method or methods.

The design and selection of a more comprehensive set of test cases ensures that the computational complexity is assessed for a wide variety of scenarios. In the composition of the test cases the different applications of pedestrian models and the properties of the different types of models that might affect the computational complexity are taken into account. This ensures that users can more fairly and systematically compare the complexity of different models and can obtain good insight into how a pedestrian model would perform in different situations.

To assess the framework, the computational complexity of a selection of models is assessed with different goals in mind (e.g. comparing different conceptual models or obtaining the computational complexity of a specific model and implementation). The assessment shows that the selection of teste cases has a big impact on the complexity of models. This, in turn, illustrates the importance of the systematic approach to assess complexity. The results also show the high dependency of a model's complexity on its exact software implementation (e.g. coding language, mathematical procedures, algorithms) regardless of the applied conceptual method. In short, assessing the computational complexity of pedestrian models is itself complex and requires a systematic approach and thus a framework to guide a modeller or model user.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Benchmarking a flow prediction algorithm for indoor spaces: Graph-based Neural Network approach

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Crowd management is an essential aspect of urban planning and emergency, as it helps improve the safety and experience of visitors. Accurate prediction of crowd flow is crucial for venue operators to respond effectively to large crowds. By predicting and managing crowd densities, venue operators can take appropriate measures to ensure the safety and well-being of visitors.

Recent research has focused on predicting crowd flow at a city-wide level, Ref. [1, 2] but there is little research exploring the use of data-driven methods to predict crowd flows at indoor venues such as train stations, airports, and shopping malls. In this work, we are leveraging modern data-driven methods and AI techniques to establish a crowd flow monitoring system that predicts the crowd flow of people inside a building. We formulate this problem as predicting the pedestrian flow at different regions inside the building at the next time steps. The time-series flow information is obtained by the sensor network. We utilize the Graph Network to capture the spatial information of the building and perform the flow prediction task. Although there are a lot of mature traffic and crowd flow prediction approaches, there's no previous work using these methods for indoor pedestrian flow prediction, which means the predictability of the graph-based neural network remains unknown in this domain. A benchmark is necessary for evaluating these methods in terms of prediction accuracy and usability. To this end, we are utilizing the digital twin technique to build up a synthetic dataset and simulate the pedestrian's movement inside a train station (Fig. 1) using the simulation software Pedestrian Dynamic.

There are two types of data that would be generated: the time-series crowd flow data recorded by the sensor network and the trajectory data of the pedestrian. The flow prediction would be directly based on the historical flow data, and the ground truth OD matrix would be generated based on the trajectory data for further investigation. By modifying the predefined OD matrix of the simulation system, we are able to simulate different scenarios of the crowd moving into the station. We are also designing an array of evacuation scenarios, in which the crowd is required to completely evacuate the building. With

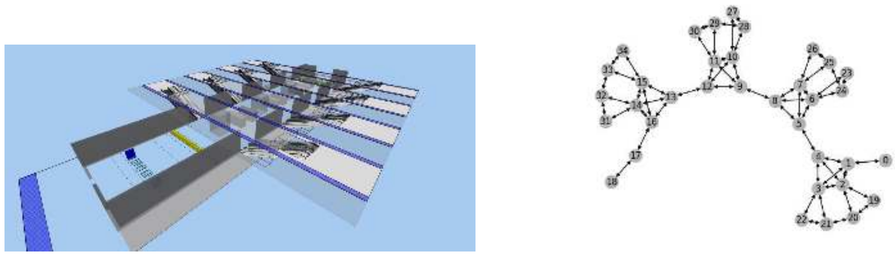

Figure 1: A Visualization of the train station model and the sensor network.

these synthetic datasets, we are evaluating different prediction models using the Graph Network and comparing them with traditional methods like VAR, ARIMA, and RNN to find out what the crucial factors for indoor crowd flow prediction are. We will also propose a new evaluation metric, which could be more practical than the widely used RMSE, MAE, and MAPE which are only suitable for average performance evaluation.

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Single-file motion revisited: perspectives from an energy-based model

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Endeavors to model the movement of crowds have thrived in recent years, partly due to the growing enthusiasm since the end of the covid 19 pandemic for crowded social events, for which safety rules need to be improved. However, there is still no consensus on how to classify these models in an unambiguous way. Thus, many descriptive models came up, based on the social forces model, sometimes introducing multiple parameters and trying to reproduce as well as possible classical observables in crowd dynamic such as the fundamental diagram linking average speed and density **[1,2]**. These models have the major drawback of not being able to be applied to a wide range of scenarios. The multiplication of parameters also makes it very difficult to determine the precise role of each in the overall dynamic. Microscopic behavioral models have therefore emerged that are more general because they depend little on the scenario studied. This is the case of this behavioral anticipation model based on an energy formulation **[3]**. At each iteration, the pseudo-energy of the system is computed and minimized with respect to the different degrees of freedom of the system, i.e. the candidate velocities of all pedestrians who move accordingly. These models have the additional advantage of being numerically very stable and therefore easier to integrate. We present here a further development of this behavioral model. To understand precisely the function of each parameter, we first studied it in the context of one-dimensional scenarios where pedestrians walk in a line without crossing each other. In this framework, it is well known that collective stop-and-go phenomena emerge. A linear stability analysis allows us to find the critical density at which they appear with only an inertia parameter to fit. Indeed, as our model is general, the parameters apart from the inertia were first measured in various other one-dimensional scenarios. The fundamental diagram is also reproduced. We rely on experimental data from a team of Juëlich **[4]**.

Let us be more precise. The behavior of each pedestrian can be broken down into two blocks. The first one is decisional. After estimating the speed and position of surrounding neighbors, each pedestrian updates its own desired speed with a certain reaction time, minimizing a pseudo-energy. This pseudo-energy includes a biomechanical term reflecting the desire to reach a specific destination as quickly as possible (or to do as much tour as possible **[Fig. 1]**), an avoidance term based on the estimated time before collision with a pedestrian present in the field of view, and two psychological terms, one indicating a reluctance to change one's current speed and the other a desire to preserve one's personal sphere from possible intrusion. The second block describing the behavior of our pedestrian is mechanical. It confronts desires with reality. Each pedestrian will accordingly adapt his real speed to tend towards this desired speed after some characteristic time, known as the mechanical time, a parameter of the model. For the sake of simplicity, we do not include in this 1d version of the model any mechanical repulsion forces. In summary, this paper demonstrates the predictive and descriptive potential of a behavioral approach to modeling pedestrians in 1-dimensional queues first and then in more advanced 2-dimensional scenarios.

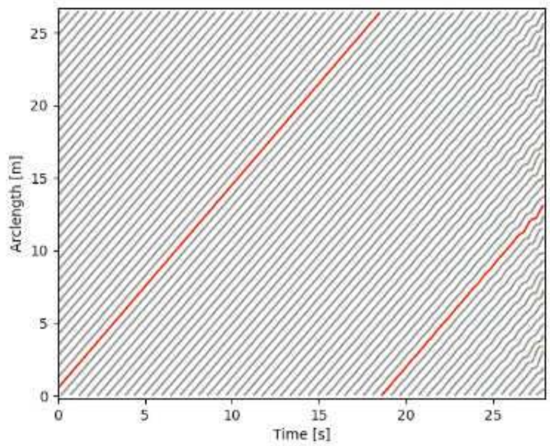

Figure 1: Left panel: simulation of pedestrians walking in single file made with CHAOS. **Right panel:** pedestrian trajectories from the left panel, initially spaced the same distance apart, moving at their equilibrium speed perturbed by a white noise in space coordinate. The trajectory of the pedestrian with a red star over it is drawn in red. Towards the end of the trajectory, stop and go waves can be seen.

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Modelling tourists movement considering different arrival modes and time constraints

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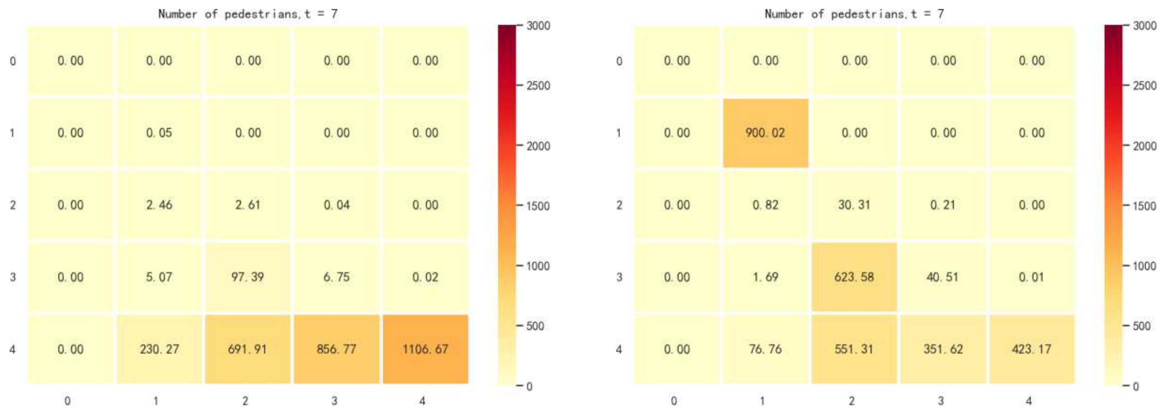
Recently, the frequently happened stampede of tourists in urban public spaces resulted serious deaths and injuries. For example, a massive crowds celebrating Halloween in Seoul became trapped as the crowd surged into a narrow alley, killing at least 158 people and injuring 151 others in South Korea in 2022. The lack of knowledge of the spatial and temporal distribution of crowds in the event area was the main cause of these accidents. When pedestrians are in the sightseeing/stroll, their route choice strategy differs significantly from the evacuation/commuting. For instance, pedestrians prefer to take a detour to see beautiful scenery or stopping a walk to watch a street performance, in addition to usual goal-oriented behavior. These are route choice strategies under the points of interest (POI) conditions. Existing studies on this type of walking behavior mainly focuses on the influences of POI under the assumption that pedestrians with the same arrival moment and time constraints [1]. However, pedestrians usually arrive at various time and are highly heterogeneous in reality, meaning that different categories of people can stay for different lengths of time. It is thus that simple statistical characteristics cannot appropriately describe the spatial and temporal distribution of touring crowds within public spaces, which creates a lot of uncertainty in the crowd risk regulation.

Therefore, based on the multiclass POI-based route choice strategy, we propose a model for tourists movement to solve the above problem. In this model, the arrival modes (i.e., moments of pedestrians arrived at the initial position) of pedestrians subjects to the Poisson distribution with the parameter λ, and each group of crowds has different time constraints T. In Fig.1, a comparison of the tourists distributions under different arrival modes and time constraints at time step $t = 7$ is exhibited. We assume that $(0,0)$ is initial position, $(4,4)$ is destination, $\{(2,2),(3,2)\}$ are points of interest and the total time of the simulation is $T_{total} = 10$. From the figure, we find that differences in the number of arrivals N at each moment and the heterogeneity of the time constraints will lead to the variation of high-density regions. The proposed model could better reproduce the real-time distribution of crowds under various arrival time and different time constraints and thus providing a scientific way to managing tourists.



a) Pedestrians arrive at initial position $(0,0)$ at $t = \{0\}$ with $N = \{3000\}$ and $T = \{10\}$.

b) Pedestrians arrive at initial position $(0,0)$ at $t = \{0,2,4,6\}$ with $N = \{1000,500,600,900\}$ and $T = \{10,7,5,4\}$.

Figure 1: Tourist distribution under different arrival mode and time constraints

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Adaptive graph weighting to support the safe navigation of heterogeneous agents through disaster scenes

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Building Information Modeling (BIM) has opened up new opportunities for indoor navigation purposes [1]. One area of application where BIM models can be used is the navigation through dynamic environments. Initially, grid-based or graph-based network models are retrieved based on the information of BIM models facilitating the utilization of standard path planning algorithms, such as Dijkstra and A*, to find suitable routes through given indoor environments.

The dynamic characteristic of the scene can be considered using a weighting approach, as introduced by Liu et al.[2]. The authors developed a graph-network model, which considers fire ignition points as hazardous threats and assigns increased weights to edges located in those areas. The optimization goal is to find the path with the lowest cost, which results in recommended paths avoiding fire ignition points.

However, the approach by Liu et al.[2] has limitations when all paths are blocked by fire ignition points. To overcome this, Dugstad et al. [3] developed a weighting methodology that does not consider obstacles in a binary way but prioritizes them with weights between 1 and 4. Those weights consider whether an obstacle must be avoided, should be avoided, whether a path through an area can be used, or even is to be prioritized. Additionally, the authors [3] proposed that the semantic information of BIM Models can be used to model the interaction between the hazardous situation and the building itself, thus improving graph weighting. Wang et al. [4] introduce a similar approach where the semantic information of a building is used to determine how long it takes to open doors of different materials within a building. By introducing time as a weighting parameter for both distance and accessibility, the path search can be optimized to find the path with the shortest time to reach a target position, considering the opening of blocked doors. While the approach by Dugstad et al. [3] shows shortcomings regarding their normalization methodology, which depends on discrete ratings between 1 and 4 and thus is less accurate than the approach by Wang et al. [4], the approach by Wang et al. [4] is neglecting safety as a weighting parameter.

In this work, we present an optimized path planning-oriented BIM-driven framework, which aims to overcome the drawbacks of the methods in [3] and [4] by integrating a weighting framework relying on safety, distance and accessibility, evaluated as a function of time. The framework a) considers multiple semantic parameters, such as fire resistance of building elements, door opening directions for flooding scenarios, and emergency routes, b) takes into account static and dynamic agent-building, agent-incident, and building-incident interactions, and c) considers different types of agents, namely unmanned aerial vehicles (UAVs), first responders, and evacuees, utilizing agent-specific user profile parameters reckoning them into the optimally safest path calculation. To calculate the optimal path, we define a new weighting methodology on the path planning graph as a function of the entire set of parameters. The weighting methodology considers accessibility and distance with regard to time and normalizes their impact regarding safety. The developed approaches are evaluated with diverse input parameters and settings.

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GoAhead: a new agent-based crowd behaviour modelling and simulator software for building pedestrian simulation

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Keywords: Pedestrian simulation, Crowd behavior, Agent-based

We present GoAhead, a high performance, user-friendly, using multi-agents technology and complete data analysis capabilities building pedestrian simulation software for general scenarios. GoAhead is designed with a scalable, modular architecture (Fig.1) with separate layers for pedestrian physical dynamics, human behaviour, data analysis statistics, and scenario design interfaces to improve stability, performance, and scalability. GoAhead is based on the ORCA[1] model and Steering Force[2] at the bottom, and we have used several innovative models (acceleration model, desired density, following path with width, asynchronous pathfinding, controlled cross-flow, etc.) to achieve more realistic crowd dynamics, which formed GoAhead's pedestrian dynamics simulation kernel. We combine behaviour trees and finite state machines to plan Agents' behaviour, more than ten types of human interaction behaviour environment models have designed and provides a nodes-link based behaviour editing tool (Fig.3). In terms of data analysis, it supports real-time density graph and up to thirty kind of real-time data extraction from simulation processes and results to create charts for analysis or export (Fig.4). In addition, GoAhead has a more flexible simulation process than other pedestrian simulators, with all changes (including obstacle updates, behaviour environment model updates, behaviour logic updates, or parameter adjustments) occurring in real time without interrupting the simulation, and all data and graphical presentations are available in real time during the simulation rather than after its completion.

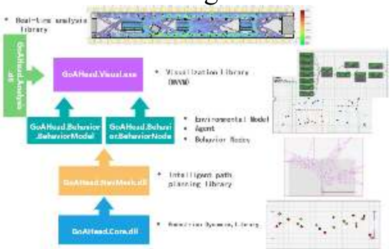

Figure 1: GoAhead's architecture.

Figure 2: GoAhead's UI interface.

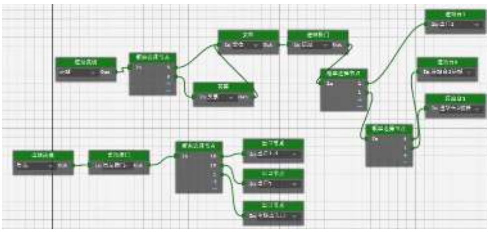

Figure 3 Agents behavior node editor.

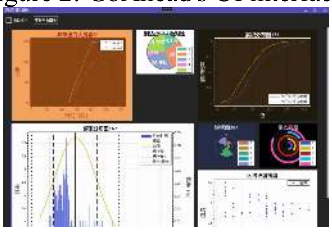

Figure 4: Real-time charts manager

As a general-purpose building pedestrian simulation platform, GoAhead is able to support the pedestrian simulation in most public buildings under normal or emergency conditions, providing support for public building design, building management, and real-time crowd management to optimize pedestrian flow in buildings and prevent and mitigate risks.

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Developing an Urban Digital Twin for Real-Time Visualization of Pedestrian Flow in Large-Scale Environments

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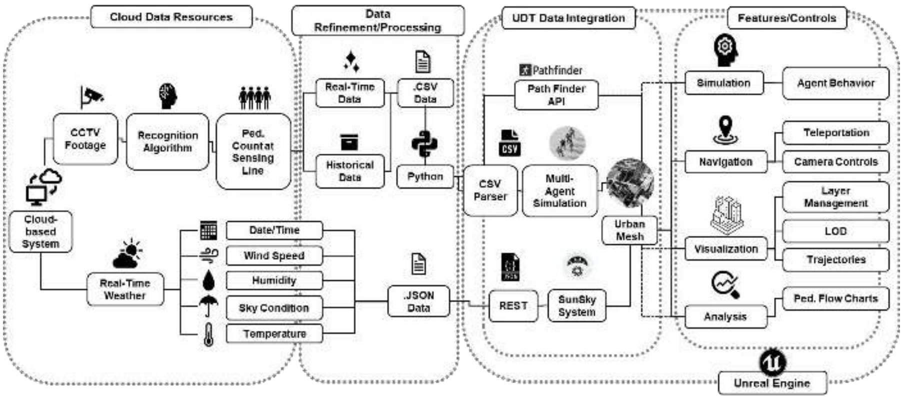

Figure 1: Structure and workflow for the proposed urban digital twin.

Urban Digital Twins (UDTs) have recently gained momentum in urban planning fields due to their ability to simulate and analyse the various aspects of a city's operation and performance, including its physical infrastructure, buildings, transportation systems, population, and economic and social activity to provide a virtual representation of a city that can be used for a variety of purposes, such as planning and design, infrastructure management, emergency response, and decision-making. In this context, utilizing UDTs as a platform to manage, visualize, and simulate pedestrian flow can provide a useful tool to identify patterns and trends in pedestrian behaviour that can inform decision-making and planning, as well as identify scenarios of congestion, and to take steps to alleviate them. Within the urban context, several studies have addressed the use of UDT for various applications, including monitoring individual mobility within the city [1], and crowded event management [2].

In this study, we demonstrate the use of a game engine (Unreal Engine 5) to create an UDT of the Tokyo Dome area in Tokyo, Japan. The aim of the developed UDT is to visualize and analyse pedestrian flow and crowd movement. The methodology and workflow for developing the UDT are discussed, as well as its features, controls, and applications. Following a field survey, a metrically accurate 3D urban mesh for the pedestrian street network, as well as surrounding built environment is realized. To visualize the pedestrian flow on the urban mesh, CCTV footage is analysed in real-time using computer vision algorithms to calculate the number of pedestrians passing through several points within the surrounding street network. Furthermore, using such data, multi-agent simulation is used to generate pedestrians in the UDT. The developed system provides several features in terms of simulation, visualization, navigation, and data analysis. The significance of the developed system lies in providing a visual tool for specialists to observe and analyse pedestrian flow patterns at different spatiotemporal settings to improve the future readability of infrastructure around the Tokyo Dome area.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Numerical and theoretical analysis of a new one-dimensional cellular automaton model for bidirectional flows

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In recent years, researches on mathematical models describing crowd dynamics have become increasingly important. Among those researches, one of the mathematical models describing bidirectional flows has been constructed and its fundamental diagram has been shown to be qualitatively consistent with the real data [1]. However, such property has not been observed for one-dimensional mathematical models [2]. In this study, we first introduce a new simpler one-dimensional cellular automaton model without body-rotation to focus only on the effect of flipping by extending the well-known ASEP as a solvable lattice model. As shown in Fig. 1, a particle determines the direction to hop with probability $p \in [0,1]$ (Fig. 1(a)) and basically hops to the cell in front with probability $q \in [0,1]$ (Fig. 1(b)) if the cell in front is vacant. The probability determining directions causes two patterns that cannot occur in ASEP: first, if one particle is facing a neighboring particle, the particles flip with probability r (Fig. 1(c)). Second, if the neighboring cell in the direction of the hop is empty, but there is a particle one cell further ahead that is facing it, one of the particles hops with probability s (Fig. 1(d)). In this research, we put $r = q^2 \in [0,1], s = q(1-q) \in [0, 0.25]$. Phenomenologically, if the particles are facing each other in close proximity, they flip when they both make a decision to move forward, and if they are facing each other at a distance, when either of them makes a decision to move forward, the one that decides to move forward hop. This model is an extension of ASEP, and the appearance of flips is consistent with the behavior of other physical models [2].

We show that the fundamental diagram in Fig. 2 obtained from numerical simulations of the new simple model without such two-dimensional information is in qualitative agreement with the real data. The mathematical model is described by an ultra-discrete equation with random variables to show that the conservation law holds, and we also compare the simulation results with flow rates obtained theoretically using the stochastic transition matrix of states [3] for 4cells/6cells with the periodic boundary condition.

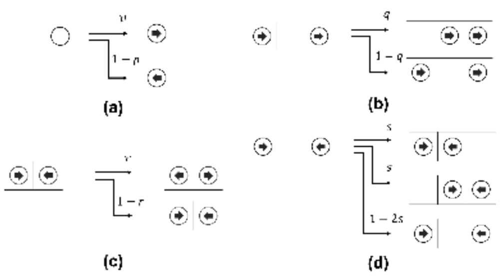

Figure 1: Illustration for each probability.

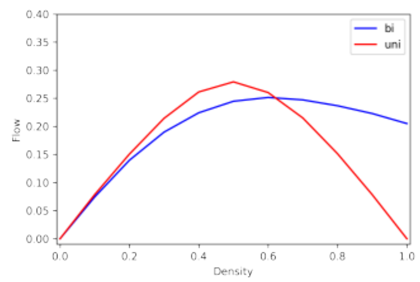

Figure 2: Fundamental diagrams of our model. The graph drawn by the blue line and the red line shows the average flow of the bidirectional flow for $(p, q) = (0.8, 0.8)$ and the unidirectional flow for $(p, q) = (1, 0.8)$, respectively.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Disassembling JuPedSim:Easier Modeling and Integration by Providing a more Versatile Pedestrian Dynamics Simulation Library

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The JuPedSim project, actively developed since 2012, was initially created as an application-based suite of tools to facilitate research into pedestrian dynamics. Despite its promising start, development efforts experienced a slowdown over the last 18 months due to a host of challenges that hindered the project's progression and usability. These challenges ranged from complex configuration procedures and software rigidity that limited user engagement, to significant difficulties in extending simulations for innovative research.

The JuPedSim software, originally built using C++, had several inherent drawbacks. Its use of C++ as a development language greatly narrowed the potential contributor pool, as not all researchers had proficiency in this language. There was a lack of clear distinction between core and experimental components within the codebase, making code navigation and extension an arduous task. Furthermore, long-standing feature requests such as the ability to store and resume simulations, and the provision of the simulation core as a library for use in other projects, remained unaddressed. Additionally, the software occasionally crashed or erroneously removed agents, impeding its reliability.

Recognizing these challenges, the team attempted a complete redesign of the software. However, the process of building an application from scratch proved more daunting than expected. The developers faced issues in skillset compatibility, coordination of part-time developers, and simultaneous maintenance of the old JuPedSim to support ongoing research. After a year of development without a viable replacement software, the team was compelled to rethink their strategy.

Despite these challenges, the rewrite efforts were not in vain. The process led to a significant learning curve and yielded beneficial prototypes for the future. It revealed the need for a target architecture that would allow the command-line interface simulation tool to function as a library. It underscored the importance of easy integration into other languages, especially Python, to widen the potential user base and streamline the development process. It also highlighted the importance of reproducibility and a flexible design that would facilitate easier extensions with new algorithms.

Drawing upon these insights, the team has now shifted its focus towards refactoring the existing JuPedSim code instead of rewriting it from scratch. This approach, although potentially more time-consuming, ensures the availability of a functional software throughout the process. This strategic transition aims to create a more flexible, user-friendly, and efficient tool for pedestrian dynamics research, by wrapping a C++ library in Python, and introducing a modifiable state during runtime. Initial steps have already been taken with the refactoring of the visualization tool, jpsvis, demonstrating a promising start to this new strategy for software enhancement.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Maximum walking speed of nursery workers handling multi-passenger strollers until exhaustion on a steep tsunami evacuation slope

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Nursery schools located in tsunami hazardous areas in Japan tend to set evacuation plans in which nursery workers carry infants to safe areas using multi-passenger strollers, which can weigh over 100 kg with up to 8 infants on board. As noted in Ref [1], during the 2011 Tōhoku earthquake and tsunami, when the shortest Available Safe Egress Time (ASET) was 25 minutes, the effectiveness of evacuation was impacted by the capability of workers communicating and handling strollers on slopes with inclination up to 8%. However, there are not enough studies under more extreme conditions in terms of ASET and steeper slopes. There is also a need to develop and improve crowd evacuation simulation models, including those proposed in Ref [2], among others, in a way that also considers adverse factors such as physical fatigue.

As the first study focusing on tsunami evacuation under extreme conditions, this research analyses the walking speed of nursery workers handling strollers until exhaustion on a steep slope, by conducting a series of evacuation experiments in Wakayama Prefecture, Japan, between 2021 and 2022. Assuming the occurrence of the Nankai thrust earthquake with 6 minutes of ASET, 32 workers aged 20s-60s old and 154 children aged 0-6 old participated in experiments. Children were evacuated to higher ground through a slope with 83 meters of distance and 12 meters of elevation, with 15%+ inclination. Five strollers, each one handled by 2-5 workers (subjects), transported infants under 1 year old (Fig. 1). The speed of subjects was measured by their trajectory processed from tracking cameras and aerial imagery using an unmanned aerial vehicle (drone). Their physical fatigue was analysed by exercise intensity data acquired with heart monitors.

As the main findings, the average of walking speed by subject per each measurement segment was 0.8-1.5 m/s (SD=0.1-0.3). In the fastest case, the speed tended to reduce by about 5% for each 1-meter rising. The speed was also impacted by the number of subjects handling stroller together, and the flow of children over 2 years old walking around. About half of the subjects reached high level of exercise intensity, surpassing the estimated anaerobic threshold (AT=80%) and presenting signs of respiratory distress. These findings can be crucial to evaluate the effectiveness of evacuation plan in facilities under risk of tsunami.

Figure 1: Walking speed and exercise intensity of a nursery worker handling stroller on a steep slope (sample).

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Single-file Pedestrian Dynamics with Follower Interactions

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Single-file movement in pedestrian dynamics is when people walk one behind the other in a narrow space like a corridor without overtaking. Researchers study this kind of movement to understand how people move in crowds. They conduct experiments in closed spaces to keep the conditions simple and focus on the significant aspects of pedestrian's movement. Thus, one-dimensional modeling is a matter of great interest to researchers. They focus on how the speed of pedestrians relates to the distance from neighbors, as well as how it relates to the formation of stop-and-go waves. Most models in the literature only consider the distance and relative speed between a pedestrian and the person directly in front rather than considering the interactions with people on both sides. This is known as "totally asymmetric" modeling. In [1] the authors show that the distance behind simultaneously with the distance in front improves individual pedestrian speed predictions by 18% compared to forward distance alone. The aforementioned result inspires the authors to extend the interaction in the stochastic optimal velocity (OV) model [2] with the pedestrian behind. In the proposed symmetric model, the speed depends on the distance to the pedestrian in front and the relative distance between the pedestrians in front and behind:

$$\begin{cases} \dot{x}_n(t) = F\big(\Delta x_n(t) + \alpha(\Delta x_n(t) - \Delta x_{n-1}(t))\big) + \xi_n(t), \\ d\xi_n(t) = -\gamma\xi_n(t)dt + \sigma dW_n(t). \end{cases} \tag{1}$$

The parameter α can be adjusted to give more or less weight to the distance with the person behind. We compare the simulation results of the improved model to the original totally asymmetric approach for different settings of α. The simulations for positive α show fewer backward movements, making the stop-and-go waves qualitatively more realistic. Furthermore, we found that the symmetric model with selected values for α better describes the fundamental diagram (space-speed relationship) and its scattering.

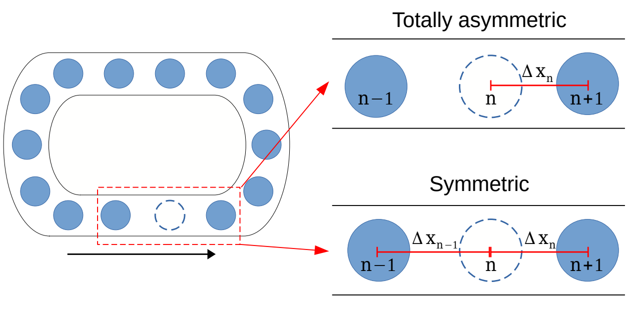

Figure 1: Scheme of the single-file movement system and models. Δx_n and Δx_{n-1} are the distances in front of the subject and follower pedestrians, respectively.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Ab initio quantification of the risks of viral transmission in pedestrian crowds using empirical data or simulated trajectories

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Detailed information about the microscopic dynamics of pedestrians in diverse settings, beyond the average density and flow rate, is of course instrumental for the design of new public spaces. But it has also turned out to be critical for a proper assessment of the risks of viral (e.g., COVID-19) transmission in various types of crowds, especially via the short-range airborne route. Still, even if such detailed information is avaiable, in order to assess the risks associated with this pathway in pedestrian crowds, there remains the considerable challenging of bridging the chasm between (microscale) fluid dynamical simulations and (macroscale) population-scale epidemiological models.

We have achieved this by
(i) simulating droplet trajectories at the microscale in numerous ambient flows (see examples on the figure) with direct numerical simulations,
(ii) coarse-graining their results into spatio-temporal maps of viral concentration around the emitter,
(iii) coupling these maps to field-data about pedestrian crowds in different scenarios (streets, train stations, markets, queues, and street cafés), and
(iv) deriving the risks of new infections on the basis of a Wells-Riley-like equation.

At the individual scale, our results highlight the paramount importance of the velocity of the ambient air flow relative to the emitter's motion. This aerodynamic effect, which disperses infectious aerosols, prevails over all other environmental variables. At the crowd's scale, the method yields a ranking of the scenarios by the risks of new infections, dominated by the street cafés and then the outdoor market [1, 2]. While the effect of light winds on the qualitative ranking is fairly marginal, even the most modest air flows dramatically lower the quantitative rates of new infections [2].

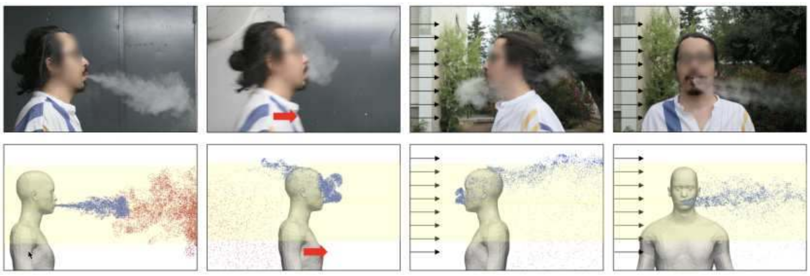

Figure 1: Respiratory droplets exhaled by a static or walking pedestrian, depending on the external wind. (Top row) Photographs. (Bottom row) Fluid-dynamical simulations.

The foregoing practically important results were derived using real (empirical) data containing an exhaustive set of pedestrian trajectories and head orientations, but one may wonder if the output of a pedestrian simulation model is reliable enough in this context, as far as the risks of transmission are concerned. To answer this question, we will compare results generated with our very recent versatile agent-based model [3] and those obtained with traditional agent-based models. These steps will be performed on a numeric platform based on our Python scripts, which will be made openly available.

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Assessing Crowd Forces within an Agent Based Pedestrian Model

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It is recognised that it is not just the density of the crowd, which impacts risk, but also the activity of the crowd. In a static crowd, increased densities are not always synonymous with risk. Sometimes, the audience might even favour higher densities for example, at a pop concert where local densities can reach in excess of 5-6 people per metre square. On the other hand, architectural features and structures that restrain occupants in inadequate spaces or force crowds to move through bottlenecks can cause the crowd to reach critical densities, thereby causing major pedestrian discomfort or even injuries, such as a crowd crush. In order to enhance the understanding of the level of comfort experienced by a person in a crowd, this work outlines a new concept called Levels of Crowd Force (LoCF) that measures the relative contact forces between pedestrians in an agent-based model. This capability to determine contact forces between pedestrians provides an additional measure that goes beyond the traditional Level of Service, as it provides a more detailed representation of the true comfort levels of the pedestrians, based on the forces experienced, which goes beyond just a simple measure of density. The LoCF functionality is implemented within bEX-Continuous[1]. The crowd force model in bEX-Continuous includes a mechanism for calculating the forces exerted on neighbouring agents in heavily crowded scenarios. Fig. 1 presents an agent P in contact with neighbouring agents A, B and C. Fig 2. illustrates the variations in agent colour in the crowd force model, depending on the level of force experienced.

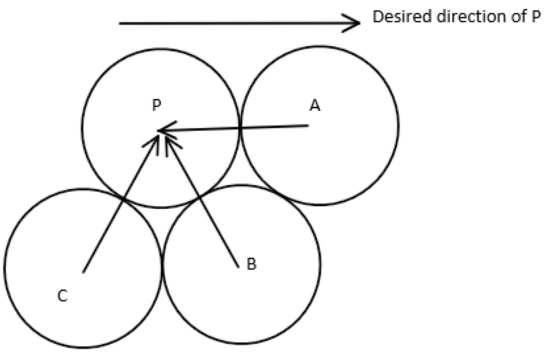

Figure 1: Calculating crowd forces in the bEX-Continuous model

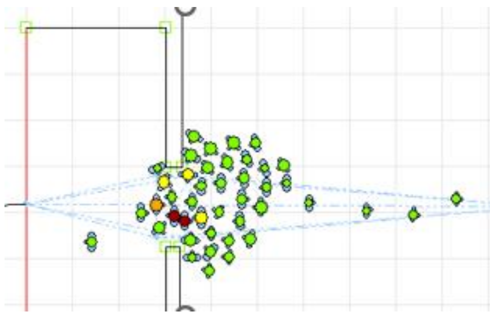

Figure 2: Crowd pressure model in bEX-Continuous

The crowd forces are calculated based on the mass of the agents and the change in velocity of the agent P when it comes into contact with neighbouring agents A, B and C. Moreover, the crowd force model also monitors the duration during which the agents are exposed to different force levels namely high forces, moderately high forces, medium forces and low forces. The categorisation of the force levels is based on empirical observations [2]. The method presented here allows modellers to rank the simulations not just on the evacuation times but also, on the levels of forces that are experienced by the agents. This implies that scenarios which allow the quickest evacuation, whilst not exposing the occupants to dangerously high levels of crowd forces, can be selected.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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A Full-Coupled “Computational Fluid Dynamics – Cellular Automaton” Evacuation Model in Fire

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Most evacuation models focus on pedestrians’ movement but neglect fire’s influence on their decision making and trajectories. To point out, with the intervention of fire, occupants’ evacuation will be largely affected when the fast development of fire becomes a serious threat during occupants’ movement i.e. some area will be filled with smoke and people could not walk through but have to make a detour instead. Therefore, in this paper, we proposed a full-coupled “Computational Fluid Dynamics (CFD) – Cellular Automaton (CA)” evacuation model in a tunnel fire. Compared to most human behaviour models, our model could estimate pedestrian dynamics in fire precisely and accurately, and will lead to an smart and scientific evacuation strategy and plan in fire. Thus, it could be applied to improve and optimize building facilities and intelligent rescue plans further.

The model owns three parts, see Figure 1. Fire dynamics are simulated via CFD modelling. The data extracted from CFD models are imported into CA models and considered in agents’ decision making and movement as the moving rules. Each agent’s force is calculated as Eq. (1), and each agent move to the optimal cell for each step following maximum likelihood estimation.

$$F = f(S, E, SI, \sum_{1}^{N} f_i) \quad (1)$$

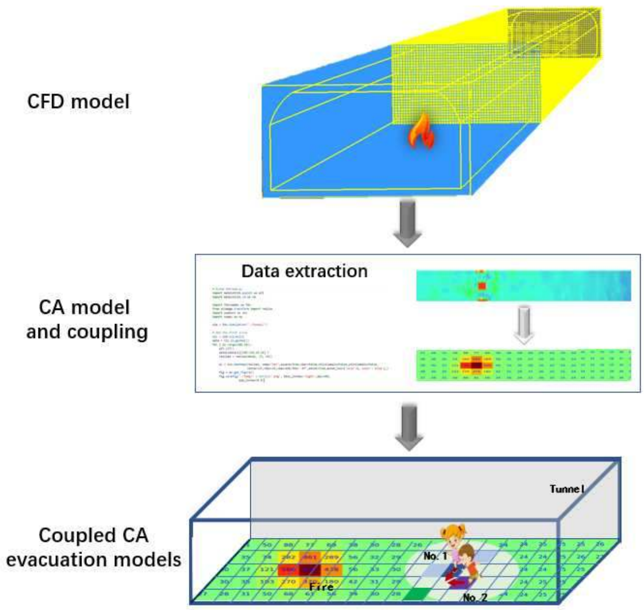

Figure 1 The diagram of a full-coupled “CFD-CA” evacuation model

The paper proposed a full-coupled “Computational Fluid Dynamics – Cellular Automaton” evacuation model in a tunnel fire. During the evacuation process, the influence of fire is thoroughly considered, and it contributes to intelligent evacuation plan in the future.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Investigating Pedestrian Crowd Characteristics in the Vicinity of a Stadium after Large-Scale Events for Multi-Agent Simulation

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The management of crowd dynamics within stadiums during large events is a critical challenge, as congestion in pedestrian streets leading to public transportation can lead to severe accidents (e.g., Akashi, 2001; Itaewon, 2022). Multi-Agent Simulation (MAS) has been identified as an effective tool for crowd management planning and safety assessment (Sidiropoulos et al., 2020) and has gained significant attention in recent years for real-time crowd monitoring and forecasting. Our research team has developed a digital twin that accurately reproduces the geometry of the pedestrian streets surrounding the Tokyo Dome in Japan and a framework for real-time crowd simulation while concurrently collecting data on human flows within the vicinity of the stadium (Yasufuku, et. al 2022). The primary objective of this project is to provide each pedestrian with congestion forecast information post-event, during which time congestion is likely to be at its peak as individuals make their way home. However, there are several challenges that need to be addressed in order to achieve this goal.

First, despite the abundance of research on crowd control during evacuation scenarios (Siyam et al., 2020), studies on crowd control under normal conditions are limited, thus there is a lack of understanding of crowd characteristics such as walking speed, queue density, and route choice, among others. Second, the complexity of route choice poses a challenge in crowd control under normal conditions. In contrast to evacuation simulations, where agents are typically assigned a common behaviour of moving towards designated safe exits or locations, outdoor walking routes under normal conditions are diverse and complex, thereby complicating the parameters that must be assumed in simulation models. Additionally, it is infeasible to track the trajectory of all individuals within a large outdoor space. As a result, the prediction of the number of pedestrians reaching a destination, such as a train station or bus stop, must be based on limited data collected at specific locations.

The objective of this study is to determine the simulation parameters necessary for real-time forecasting of pedestrian crowd dynamics in pedestrian streets surrounding stadiums where large events are regularly held under normal conditions. This will be achieved through the measurement and survey of crowds in these streets, as well as the implementation of simulations utilizing this data. First, an area including the assumed main routes home were established, and cameras were installed at key locations to capture images of pedestrians. The video images were then analysed to gather data such as pedestrian flow and density in a real-world environment. Subsequently, utilizing the data obtained at the starting line as input, simulations were run towards the goal line in various scenarios, adjusting the parameters such that the simulation results at the goal line match the measured results as closely as possible. The results of this study demonstrate the need for adjustments in parameters such as queue density, personal distance, and walking speed, and the variability of route selection scenarios depending on the number of visitors and the type of event. This research contributes to the planning of crowd control in outdoor spaces under normal conditions and emphasizes the advantages and limitations of utilizing crowd simulation in pedestrian streets.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Empirical analysis on external factors affecting pedestrian dynamics in high-density situations

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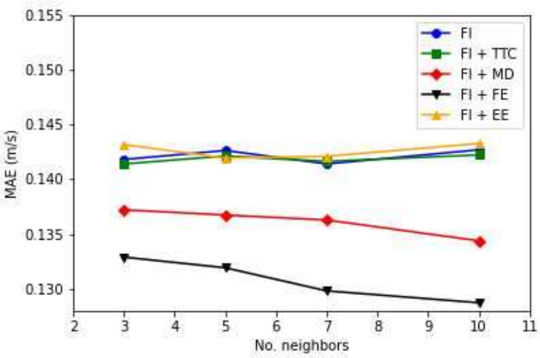
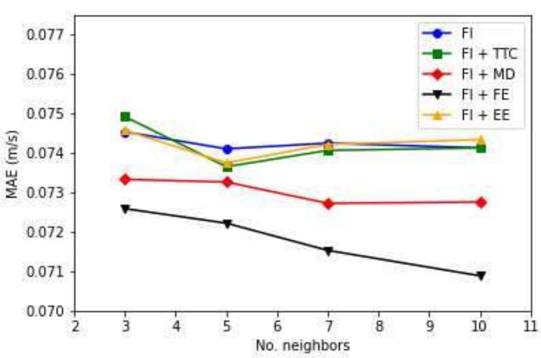
Predicting pedestrian dynamics in crowded environments is a complex task as pedestrian speed is influenced by multiple external factors. In this study, we aim to examine external factors that affect pedestrian walking speed in dense situations. To this purpose, we propose a set of prospective variables, including Mean Distance (MD), Environmental Effect (EE), Frontal Effect (FE), and Time-to-Collision (TTC), and evaluated their impact on pedestrian speed using a machine learning approach on the high-density Jülich dataset [1]. The data for each variable, combined with fundamental inputs (FI) such as current speed, relative distance, and relative velocity of neighbors at time t, is fed into a neural network for training and predicting pedestrian walking speed at time $t + \Delta t$. Furthermore, a sensitivity analysis is conducted to determine the relative importance of these variables and identify the key factors that have greatest impact on pedestrian speed. Finally, the results are compared to those in low-density datasets [2, 3] to evaluate the difference between low-density and high-density circumstances. Our findings on the Mean Absolute Error (MAE) results of the prediction of pedestrian speed (as seen in Fig. 1) demonstrate that the Frontal Effect and Mean Distance are effective indicators as they exhibit a noticeable improvement in accuracy in both unidirectional and bidirectional scenarios in the Jülich datasets, whereas better results could not be observed from other factors. These insights can be utilized to improve the accuracy of pedestrian dynamics predictions in high-density situations by incorporating these factors as additional features in the model.



(a) Unidirectional flow, $\Delta t = 0.4s$.



(b) Bidirectional flow, $\Delta t = 0.375s$.

Figure 1: Results on the Jülich datasets [1].

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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A Novel Boarding Method for Blended Wing Body Passenger Aircrafts

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Aircraft boarding could be impacted by multiple factors, including boarding method, passenger behaviours, amounts of hand luggage, as well as the cabin layout. Whereas boarding of conventional tube-and-wing aircrafts are already extensively studied, the influence of boarding methods on future blended wing body (BWB) passenger aircrafts are less explored. In this study, a BWB passenger aircraft boarding simulation environment is used to evaluate the effectiveness of a novel boarding method based on the traditional *Steffen Perfect*. The novel boarding method, named as *Alternating Order Steffen*, could significantly reduce the boarding time if applied properly.

The boarding model is based on the cellular automaton model that has been widely applied in simulations of boarding as well as other forms of traffic flows. As a time-discrete model, agents will be activated randomly during every timestep for moving towards their assigned seats. The model contains the BWB passenger aircraft and a small part of the boarding bridge. The cabin itself is divided into three bays, each with its own aisle, which are connected to the main aisle on the left. The boarding problem could be largely simplified by organizing 288 passengers in the modal into 36 mini-groups. How passengers in the left bay are organized into 12 mini-groups is shown in Figure 1. Similar mini-groups (mini-group 13–36) are also applied in the other two bays.

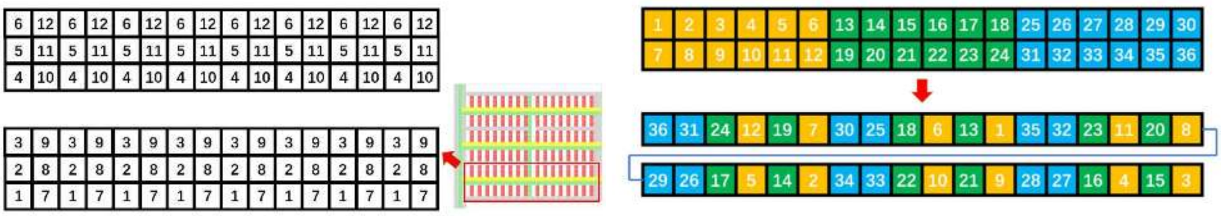

Figure 1: Simulation model and how mini-groups in *Alternating Order Steffen* are organized (left), and the boarding order of 36 mini-groups in *Alternating Order Steffen* (right). Mini-groups belonged to different bays are coloured differently (yellow: the left bay; green: the middle bay; blue: the right bay).

In *Alternating Order Steffen*, mini-groups belonged to the middle bay and the left bay will board the plane in alternating order, as shown in Figure 1. In this way, only one mini-group will try to enter the middle bay and the left bay at the same time, therefore minimizing congestions at the entrance (assuming that passengers board from the left side). Congestions at the right bay, however, is acceptable as long as the queue is not exceedingly long. By maximizing the positive effects of multiple aisles, *Alternating Order Steffen* could potentially shorten the boarding time by around 32% compared to a random boarding order. While the boarding time could still be slightly improved by splitting each mini-group into smaller groups and rearranging the boarding queue, there is no "one-size-fits-all" optimal boarding method for BWB passenger aircrafts due to an enormous amount of different cabin designs. Nevertheless, a possible "dynamic" boarding method based on bays and their distance to the entrance should be further explored, which has the potential to replace conventional boarding methods on BWB aircrafts.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Improving Agent Behavior at Stair Landings in an Agent-based Evacuation Simulator SimTread

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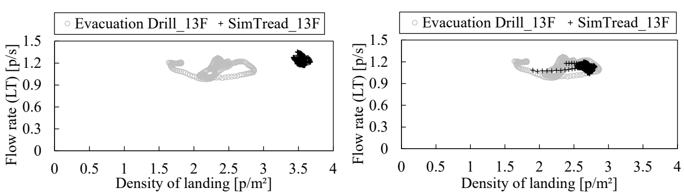
To create a rightful phased evacuation scenario, annual evacuation drills were conducted [1]. However, the annual evacuation drills required a long time and cost. Therefore, an evacuation simulation was adapted for predicting the evacuation flow in the stairwell and evaluating the evacuation scenario. Thus, the results of the calculation by the evacuation simulation; SimTread was compared to the investigation results of the evacuation flow in the evacuation drills [2]. It was found that the merge rate in SimTread was biased toward the evacuees from floors compared to the evacuation drill.

This study aimed to improve the prediction of merging flow using SimTread. Based on further analysis, improvement plans were suggested, and the developer version was used. There were two differences between the drill and simulation, and the improvement suggestions are as follows. 1) Evacuees in SimTread entered the stairwell in two lines and the door width of the stairwell on each floor should be changed to solve it because evacuees principally entered in a line while putting their hands to the door. 2) During merging, the density of evacuees at the landing by SimTread was larger than the drill as shown in Fig. 1 (a). It shall be improved by changing the personal space of the model in SimTread.

According to the first improvement plan suggested, the door width was changed from 600 to 900 mm at intervals of 100 mm. The evacuees couldn't smoothly pass the door widths of 600 and 700 mm. In a door width of 800 mm, evacuees could pass in a line, but the evacuees were often stuck at the front of a door. In a door width of 900 mm, evacuees moved in two lines the same as a door width of 1000 mm. At long last, the door width of 850 mm reproduced an evacuation flow similar to the evacuation drill (Fig. 2). According to the second plan suggested, the front length of the conflict determination area of the evacuees' personal space in SimTread was changed three times bigger than the commercialized version product, and the density at the landing and flow rate from the landing were similar to that of the evacuation drill (Fig. 1 (b)).



(a) Unadjusted model (b) Adjusted model

Figure 1 the change in the relationship between the density and flow rate

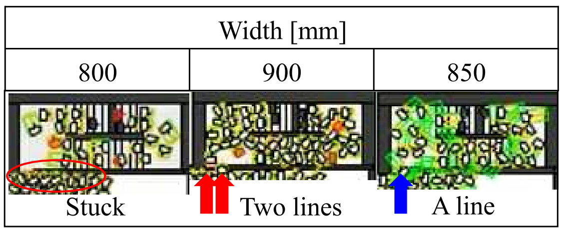


Figure 2 the changes in evacuation flow depending on the width of doors.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Tracer Observation of Queuing Behavior on New Year's Visits to Shrines/Temples Using GPS Log Data

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In Japan, people celebrate the coming of the new year by visiting shrines or temples and praying for health and happiness in the coming year. Major shrines and temples have several hundred thousand visitors over three days (New Year holidays). Having learned from past crowd accidents, the police enforces strict crowd management and have people wait in queues. However, measured data on these crowds, such as evacuation or crowd flow data, are scarce even though such data would contribute to building design for such purposes as fire evacuation, stadium design, and crowd management. As a trial to acquire crowd flow data, the author joined a queuing crowd and measured my position change over time using GPS log data as a tracer of the queuing crowd. Using this data, problems with crowd management are discussed.

The author dedicated/observed one New Year's Eve to "New Year's Day Visiting" (joining the queue at midnight on December 31 and counting down the coming of the new year, after which the queue proceeded and the author arrived at the praying place) and observed six major shrines/temples around Tokyo on New Year's Day and the next day. Figure 1 shows an example: the case of New Year's Eve to New Year's Day Visiting at a shrine/temple that has an approximately 400 m straight approach road where visitors lined up. The author entered Gate 1 at 23:16, then proceeded, was stuck at point C, and waited till 0:00, the countdown for the new year, and then again proceeded. The bottlenecks on this road were Gate 2 and the stairs to the main hall where visitors prayed. The police force deployed crowd control lines at these two points to restrict the crowd flow. When the inflow exceeds the outflow (praying people per unit of time), the queue becomes long; however, the density was almost constant (to my guess, approximately 4.5 people/m^2), because the police force restricted the crowd flows from a wide area to a narrow area and bottleneck.

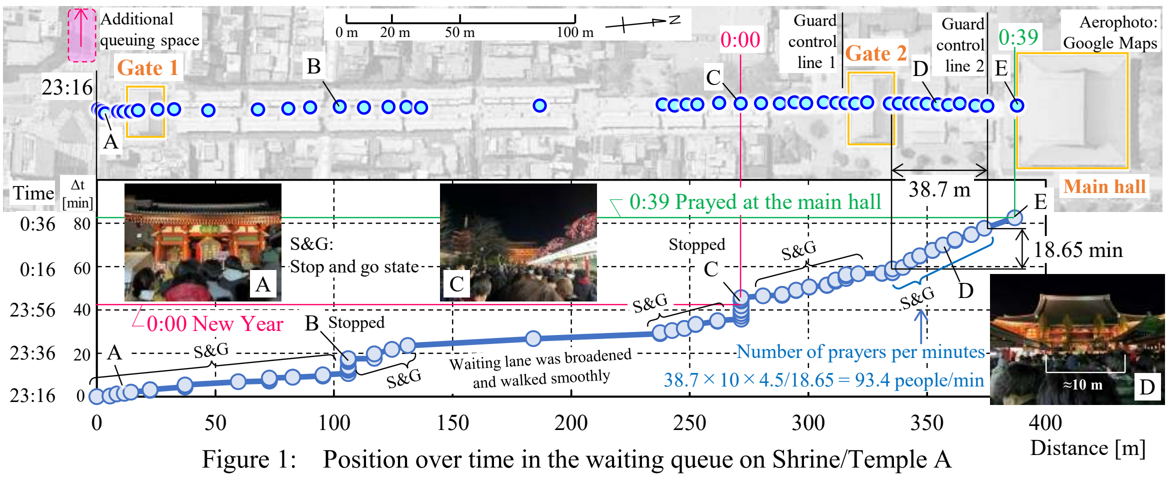

Figure 1: Position over time in the waiting queue on Shrine/Temple A

Even though the police force can estimate the number of visitors by referring to previous years; however, essentially, they cannot restrict the number of visitors. This aspect is common for some types of mass gatherings such as those at Halloween. In response, they prepare additional queuing space and have visitors wait. In contrast, in evacuation situations, such as a fire in a building, people may become upset and be hustled away for evacuation. Staff guidance is not always expected in the short term. Hence, an unsafe state such as high-density accumulation will occur. However, in buildings, stadiums, etc., the number of occupants can usually be estimated or controlled, as by the number of seats or ticketing. Therefore, to control crowd behavior, aspects of building configurations such as the widths of doors, corridors, and stairs and the areas of accumulation space should be well arranged by designers and engineers in the building design process. Each facility or event requires a different crowd management approach.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Using Dwell Time Distribution at Bottlenecks for Model Formulation and Calibration

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Using sports competition time tracking equipment Ref [1] we measured the distribution of individual dwell times in front of a bottleneck .in a lab experiment similar to previous experiments Ref [2].

Additionally, we carried out simulations with a simulation software utilising a Social Force Model Ref [3] in two variants: for the first variant A all pedestrians shared the same value of parameter tau but had different individual desired speeds v_0. For the second variant B desired speeds were varied as well, but parameter tau scaled with the value of the desired speed such that all pedestrians had (approximately) identical values for $a_0 = v_0/tau$. Variant A is a common way to work with the parameters of the Social Force Model and the flexibility for individual values it provides.

It showed – see Figure 1 – that the distribution of empirical dwell times was sharper than the distributions from the two simulation variants with variant B being clearly closer to the empirical result than variant A, while the average flow and number of people in the room was very similar most of the time for all three cases.

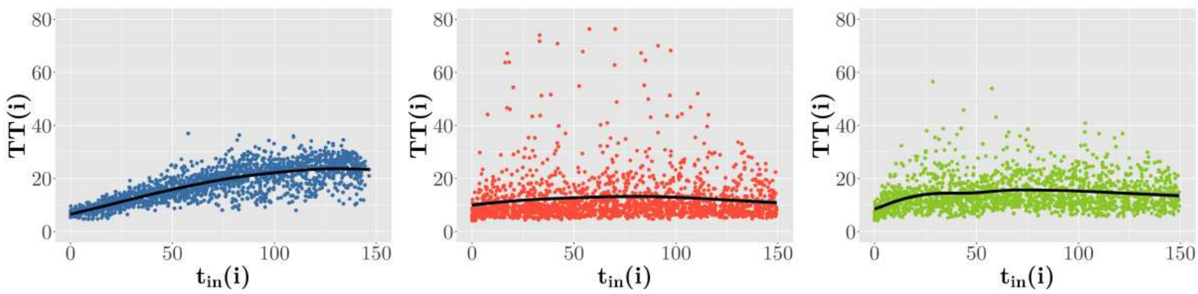

Figure 1: Dwell time vs time of entry in experiment (left/blue), simulation variant A (mid/red), and simulation variant B (right/green).

We therefore propose a reformulation of the driving force term of the Social Force Model as

$$\boldsymbol{a} = a_0\,(\boldsymbol{v_0} - \boldsymbol{v})\,/\,v_0$$

with a new free parameter a_0. Like tau a_0 could have different values for individual pedestrians, however, in the case when one value is used for all pedestrians, the simulation will yield more realistic results than when the same is done with parameter tau and the traditional formulation of the driving force term, thus making application of the Social Force Model easier.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

A subway tunnel evacuation model considering the anxiety psychology

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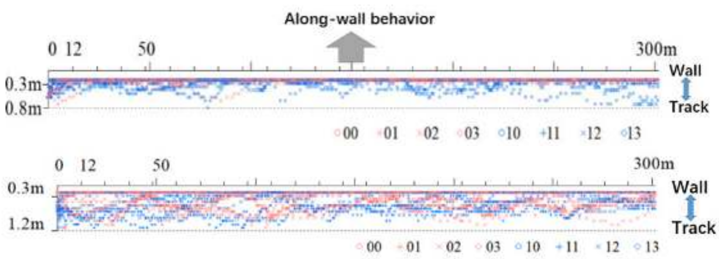
In recent years, the study of subway tunnel evacuation has attracted the attention of more and more researchers. The evacuation platform in the subway tunnel is a space which is narrow, dark and unrestricted on the track side. When moving on the platform, pedestrians may feel anxiety due to crowding, lack of reference object, and risk of falling, which has a great impact on the movement. However, previous studies on evacuation anxiety in the subway tunnels are scarce. Therefore, we build a subway tunnel evacuation model considering the anxiety psychology based on VR experimental analysis.

In this study, we conducted a VR experiment in the subway tunnel evacuation platform scenario. The experimenter's trajectory data were recorded by walking on a treadmill. A psychological questionnaire survey was also conducted. The trajectory data were used to analyze the along-wall behavior (Fig. 1) and the guidance mechanism of the evacuation sign in the subway tunnel platform. How the anxiety psychology affects the along-wall behavior and the guidance mechanism was analyzed in combination with the psychological questionnaire. Based on the experimental analysis results, a multi-velocity field cellular automaton was constructed. The anxiety indices were defined to quantify the anxiety degrees in the sign visible area and the sign blind area respectively (Figure 2), and the dynamic field of cellular automaton was improved. The model was further simulated to analyze the convergence speed, evacuation entropy and other characteristic parameters under different platform widths and sign intervals.

The experimental results show that the sign interval and the distance between pedestrians and the wall are important factors affecting the anxiety psychology in the platform evacuation.The improved cellular automaton can well reproduce the phenomenon that pedestrians converge from the initial position to a stable along-wall flow like in the VR experiment. The platform width is negatively correlated with the anxiety degrees and significantly affects the stability of evacuation. A large interval between evacuation signs can increase the anxiety of pedestrians and decrease the convergence speed. The results could offer references for improving the subway tunnel evacuation management, and also provides data basis and methods for subway tunnel evacuation modeling and simulation.

Keywords: Cellular automata, VR experiment, Subway tunnel evacuation, Anxiety psychology.

（a）



(b)

Figure 1: The pedestrian trajectory in VR experiment (a)with 0.8m platform width;(b) with 1.2m platform width.

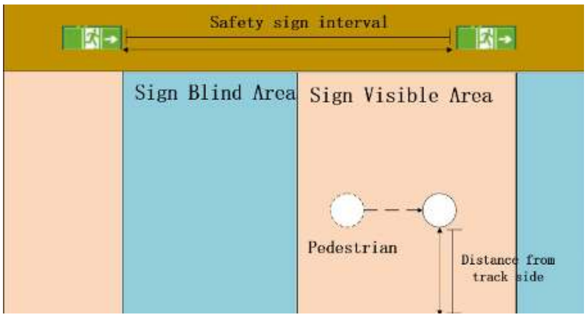


Figure 2: The sign visible area and sign blind area partition of evacuation platform

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Using time-to-collision in the loss function of deep learning algorithm to improve pedestrian trajectory predictions

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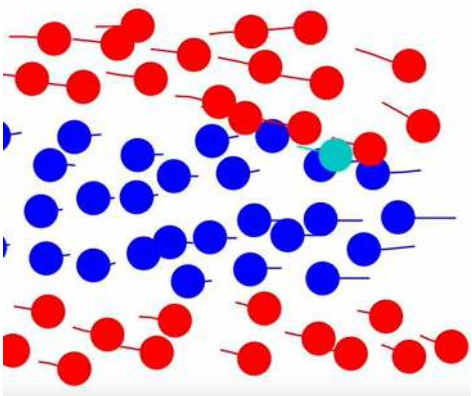
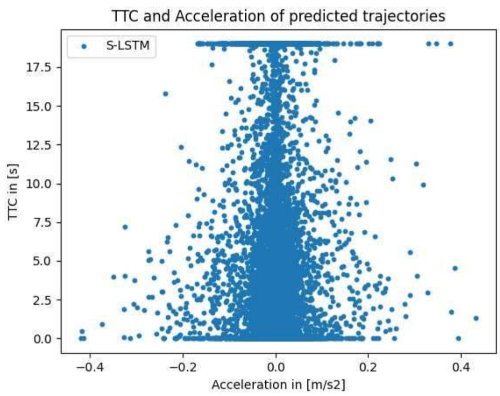
Due to numerous real world applications, pedestrian trajectory prediction has become a hot topic in the last decades. Traditionally, researchers use physics-based models to simulate and predict the behavior of pedestrians, but recently the data-based approach has gained a lot of attention [1]. In this approach, algorithms, mostly neural networks, are trained on trajectory data to predict future pedestrian behavior. The first parts of the trajectories are used as input, often over 3.6 seconds, to predict the future trajectories over the next few seconds. The evaluation is based on Euclidean distance error metrics between the predicted and real trajectories. This approach performs well in low-density situations, where just few pedestrians are involved with long range interactions. A well-known data-based algorithm is the Social LSTM by Alahi et al. [2], which shows to outperform physics-based models in such situations.



(a) With binary metric.



(b) With TTC.

Figure 1: Different ways of evaluating collision avoidance.

For high-density situations (2-8 pedestrians/m^2), commonly referred to as crowds, the data-based approach has yet to demonstrate superior performance. We argue that this may be due in part to the limitations of the Euclidean distance metric. In high-density situations, the behavior of pedestrians is mostly driven by the avoidance of touching or colliding with other pedestrian. A more appropriate way for evaluating performance in these situations would be to take collision avoidance of the predictions into account. Kothari et al. [3] introduce a binary collision metric, however, as depicted in Figure 1 (a), it is challenging to accurately define collisions in high-density situations as touches and small overlaps are prevalent. Therefore, we propose a continuous collision error metric based on the calculation of the time-to-collision (TTC), see Figure 2 (b) [4]. By jointly training the algorithms to minimize both the distance metric and the TTC, the predicted trajectories can improve in terms of collision avoidance without altering performance in terms of distance accuracy.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Verification of the Effectiveness of Evacuation Guidance in Underground Passages Using Multi-Objective Bayesian Optimization

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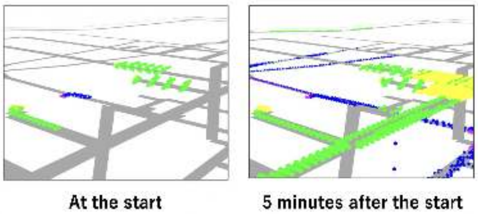

Figure 1: Evacuating simulation of CrowdWalk

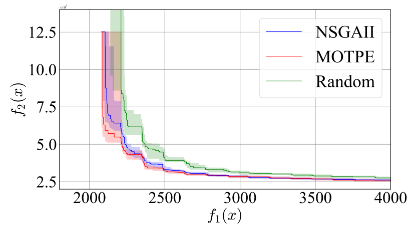

Figure 2: Pareto front

Since the Great East Japan Earthquake, the development of a well-organized evacuation plan for mitigating the effect of disasters has attracted considerable research attention. In a previous study, the guidance control around a terminal station was verified using crowd simulation, which is cheaper and less time-consuming than a real demonstration. However, the study of effective evacuation guidance methods, including underground passages, was identified as an issue to be addressed [1]. In this study, to verify evacuation guidance, we evaluate the possibility of underground passage usage in natural disaster strikes. Determining the optimal solutions that satisfy critical conditions is critical because efficiency and safety are indicators of the evacuation behavior. A multi-objective optimization problem with total evacuation completion time $f_1(\boldsymbol{x})$ and congestion degrees $f_2(\boldsymbol{x})$ as objective functions was solved using three optimization algorithms: Random, NSGA-II, and MOTPE. MOTPE, which we developed, has been shown to outperform conventional methods on many benchmark problems but has not been evaluated on real-world problems [2]. In this study, we compare the performance of MOTPE with those of Random and NSGA-II.

We simulated an evacuation from a large terminal station to a safe evacuation site located outside the station yard using the crowd simulator called "CrowdWalk" (Figure 1). Variables to be considered as guidance can be categorized into the following three categories: guidance to the turnstiles with few users, departure time difference, and underground guidance. The evaluation budget was 1,000 iterations, and 20 optimization experiments were conducted for each method.

Figure 2 displays 50 % attainment surfaces. The light color indicates the Pareto front obtained on the best and worst trials. The longer the total evacuation completion time, $f_1(\boldsymbol{x})$, the lower the congestion degree, $f_2(\boldsymbol{x})$ is. In particular, the Pareto front of MOTPE is curved closest to the Pareto optimal solution. MOTPE can search for better quality solutions than existing methods. In terms of the average value of the hypervolume per number of evaluations, MOTPE converged faster than existing methods and achieved the highest hypervolume value. The performance of MOTPE is superior to existing methods. Additionally, we compared multiple scenarios including underground guidance without induction. The results revealed that the scenarios with guidance reduced the total evacuation completion time and decreased congestion degrees. Furthermore, the results revealed that scenarios with guidance exhibited larger variable values for underground guidance. Therefore, the use of underground passages for evacuation is efficient and reduces congestion.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Influence of Configuration and Open Angle of Door on Merging at Stair Landing based on Investigation of Evacuation Drill

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The investigation of evacuation drills, which phased evacuation methods were employed on, had been conducted in two high-rise office buildings in Tokyo. In the previous research, flow of evacuees in staircase was analysed, reasonability of the evacuation scenarios was discussed to optimize them through repetitively conducted drills [1, 2]. The two buildings (hereafter, buildings A and B) had different configurations of staircases. In this study, flow rates at the boundaries around landings where the flows of evacuees met were particularly analysed under several situations.

An overview of comparative analysis is as follows. The structure of staircases in the buildings A and B differs as shown in Fig. 1. To collect the data of flows around landings, the numbers of people passing through three boundaries (dotted lines shown in Fig. 1) were counted every 1 second with time history. The numbers at the green line from the upstairs to the landing were divided into the inside of stairs U_{in} and the outside of stairs U_{out}, the number at the blue line from the floor to the landing was F, and the numbers at the red line from the landing to the downstairs were divided into the inside D_{in} and the outside D_{out}. A merging rate is defined as the value of F divided by the sum of F, U_{in} and U_{out} in this study when the flow from the floor merges with the flow from the upstairs. And, the predominated sides were analysed based on the distribution ratios of U_{in}, U_{out} and F between D_{in} and D_{out}.

The evacuees' behavior at landings, the merging rate and the proportion of D_{in} and D_{out} in U_{in}, U_{out} and F were discussed based on the analysis results. Most evacuees who passed inside of upper stairs went to inside of lower stairs through landing and the reason for evacuees taking this behavior was considered as a selective property of shorter route. And, the merging rates and the proportions of the flow (D_{in} and D_{out}) in downstream of the landing in the flow (U_{in}, U_{out}, and F) in upstream of the landing were changed according to the evacuee's behaviour controlled by the configuration and open angle of the door.

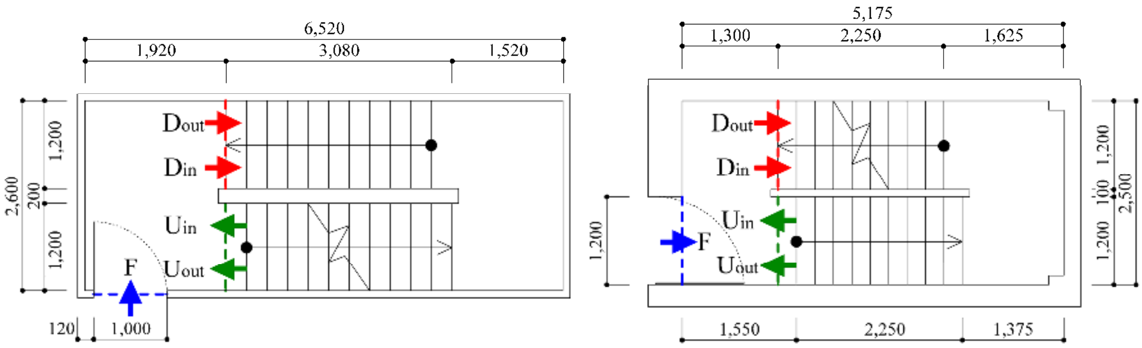

Figure 1 Floor plans of staircases in building A (Left) and building B (Right)

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Are depth field cameras preserving anonymity?

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Among the various devices allowing to track pedestrians' dynamics, video cameras allow to obtain individual trajectories, and in principle could be used in real life settings. However, they raise an issue about privacy protection. Indeed, regular videos provide in general images that allow to recognize people.

This is in favor of rather using some depth field cameras, as it was done in several experiments [1, 2]. Depth field cameras, as for example Kinect ones, measure only the distance from the first obstacle to the camera plane. If placed vertically, a pedestrian head appears as a point with maximum height (or minimum distance from the camera) that can be tracked to provide the pedestrian trajectory.

It seems that depth field measurements protect more the anonymity of people than visual images. We wanted nevertheless to test whether pixelization was needed to ensure the anonymity of people.

An experiment was performed, in which various members of our laboratory were invited to walk under a Kinect camera hanging on the ceiling. Then the depth field videos were shown to other members of the laboratory (the testers), starting with a high degree of pixelization, and improving the image quality until the tester was able to recognize his colleagues.

Surprisingly, it turns out that the degree of pixelization was not so much a relevant factor. Instead, we found that there were 2 types of testers. Some could identify colleagues even with a high degree of pixelization, others could never identify them whatever the quality of the image.

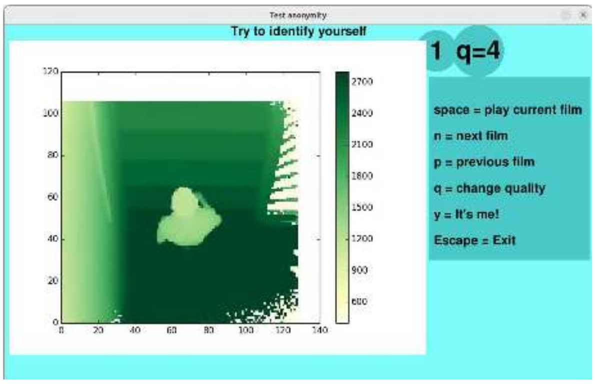

Figure 1: Interface allowing to test the impact of various degrees of pixelization onto the ability to identify oneself or colleagues.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Evaluating Jam Characteristics in Evacuation Simulations

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Standardized specifications are necessary for a reasonable configuration and evaluation of pedestrian simulations which are commonly used to verify evacuation concepts. The "Guideline for Microscopic Evacuation Analysis" (RiMEA, `https://rimea.de/`) provides a benchmark for simulation software of pedestrian dynamics.

Examining significant congestions is a key part of evaluating an evacuation analysis. Jamming can be characterized by factors such as size, time, and density, but there are no universally agreed upon thresholds for determining whether a congestion is acceptable or critical. Therefore, the evaluation of congestions is subjective and ultimately up to the individual evaluating the simulation.

In this work we conduct a simulation-based parameter study to closely investigate the dynamics of jam. Using a simplified geometry (as shown in Fig. 1), various simulations were run with varying numbers of agents and bottleneck widths (the width of the corridor). The authors of this work analyzed various factors such as area, size and shape of the jam, and evacuation time and waiting time to determine a threshold for the maximum individual speed of agents involved in the congestion. This threshold allows for a consistent definition of congestion and its evaluation for the investigated scenarios. Additionally, the study found that there are distinct static and dynamic phases in the formation of the congestion in front of the bottleneck (as shown in Fig. 2), which offers a new insight into the evaluation of congestion in evacuation simulations.

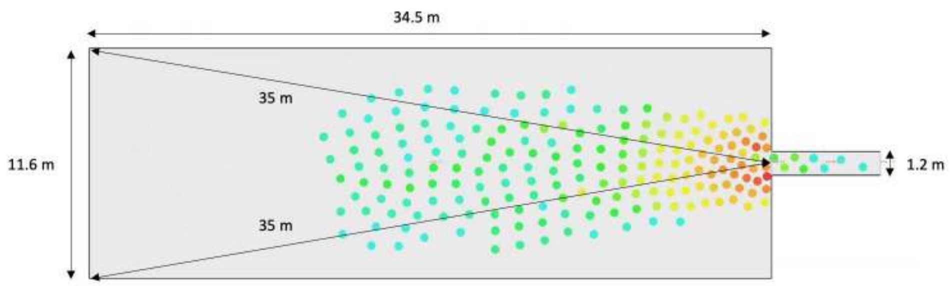

Figure 1: The simulation in the simplified geometry that was used in this study is based on the German legal building requirements for a utilization unit with office or administrative use.

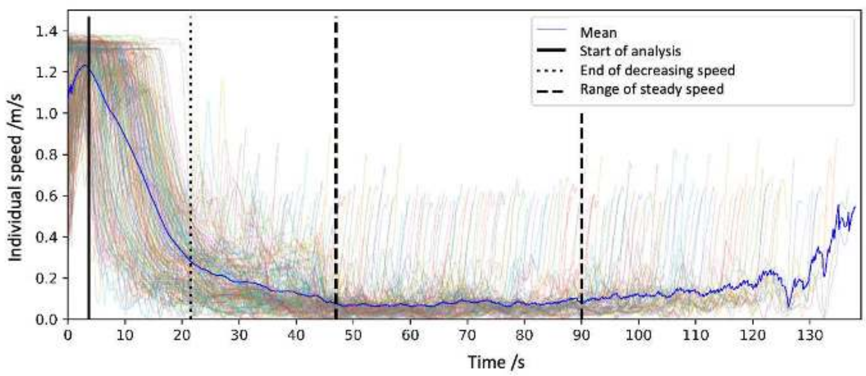

Figure 2: Individual speed of the agents in the room before reaching the corridor. Different phases are visible that come along with changes of the jam dynamics.

11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

The effect of national culture on evacuation task behaviour: a cross-cultural survey

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Human behaviour in a fire can have a significant effect on the outcome. The evacuation behaviour of building occupants consists of a response phase and directed evacuation movement phase. During the response phase, a series of information tasks (such as seeking information, actively searching for others) and action tasks (such as picking up belongings) are performed. Four main factors influencing response behaviour include culture (such as national culture), cues (such as heat or smoke), affiliation (such as being with friends at the start of the fire) and setting (such as being in a closed room or open space). Our research question is: How does culture influence response phase behaviour combined with cues, settings and affiliation? We examined this through a case study of a library evacuation. Via literature research we identified nine information and ten action tasks in a library situation, which we then used in the survey.

In the conducted survey, participants were asked which tasks they would perform and in which order for a series of scenarios. Four hundred forty-two respondents from the Czech Republic, Poland, Turkey and the United Kingdom completed the study. The main results show significant differences in both the total number of response tasks performed and the number of information and action tasks performed separately. Turkey performs the highest total number of response tasks, followed in decreasing order by Poland, the Czech Republic, and the UK. Additionally, the study showed that more information tasks than action tasks are reported for all countries, see Figure 1. Also, response behaviour in all countries is shown to be influenced by cues, setting and affiliation, as these influence the number of tasks performed and the types of tasks performed. For example, all countries perform less response tasks after being informed by staff or in case of a fire, compared to a basic scenario with a fire alarm sounding but no signs of danger, but the decrease in tasks is larger in Czech Republic than in Poland, Turkey and UK.

We discuss how the survey results can be related with Hofstede's cultural dimension scores, however these are conjectures at this moment, as yet not confirmed by empirical research. We speculate that UK showing the fastest response times might relate to the lower score on uncertainty avoidance and higher score on individualism versus the other three countries. Additionally, we speculate that collectivist cultures (of which Turkey is an example in our sample), are more likely to perform affiliative behaviour, which causes slower evacuation response times. These results can be helpful for evacuation modelling and further understanding of human behaviour in fire, see [1]. This study has shown the need for policy makers and emergency planners to discuss effects of culture on evacuations. Additionally, it provides a new approach to study the effect of cultures, in combination with cues, setting and affiliation, on response phase behaviour.

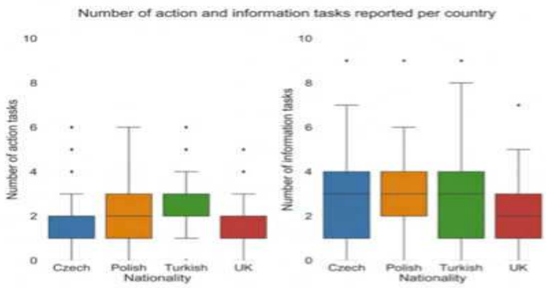

Figure 1: Box plots of the number of action and information tasks reported per country.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Incorporating Civil Protection Strategies into Urban Scale Emergency Simulation

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The emergency services have a major impact on how urban populations respond to an emergency. They need to assess the risk and coordinate an action plan to limit a hazard's impact on the local population [1]. Currently, no urban scale evacuation model exists that can explicitly incorporate the population notification procedures, define the areas at risk by the hazards, and the actions of the emergency services, who may implement a multitude of protective measures, such as standoff distances, vertical evacuation, shelter-in-place, etc [2]. Furthermore, the different forms of notification methods need to be accounted for, including basic door-to-door knocking or announcements over a tannoy, to more advanced civil alert systems, such as the 112 European emergency communication service, spontaneous evacuation or ad hoc notification performed within the local community. The aforementioned factors, along with the representation of the hazard, its impact on the population and the evacuation process need to be considered within the evacuation model, to determine the effectiveness of the employed strategy.

This paper describes the development and modelling efforts of incorporating common civil protection procedures and community responses into urbanEXODUS by utilising GIS data formats to specify model inputs. The civil protection procedures incorporated into the model were identified by the Department of Firefighters, Public Rescue and Civil Defence (Dipartimento dei Vigili del Fuoco, del Soccorso Pubblico e della Difesa Civile), Italy, as part of the EU Horizon 2020 project IN-PREP.

An area within the city of Spoleto, Italy, is used as a demonstration case, where a major incident is triggered by a vehicle accident, which results in the release of chlorine gas. The notification of the population in the vicinity of the incident is represented using formal and informal notification methods, where the local population is urged to evacuate or to head to assembly locations away from the spread of the hazard. The exposure of the population to the hazard, measured as Acute Exposure Guideline Levels (AEGLs) is used to evaluate the effectiveness of a given emergency strategy. A comprehensive analysis of over 25 what-if scenarios were preformed, varying the scenario inputs and evacuation procedures so the authorities could fully evaluate various options, hazard, whether etc. Thus, demonstrating the effectiveness of coupling notification methods, notification zones, stand-off distances and hazard propagation in a fully coupled tool, for assessing the level of protection afforded by the employed strategies.

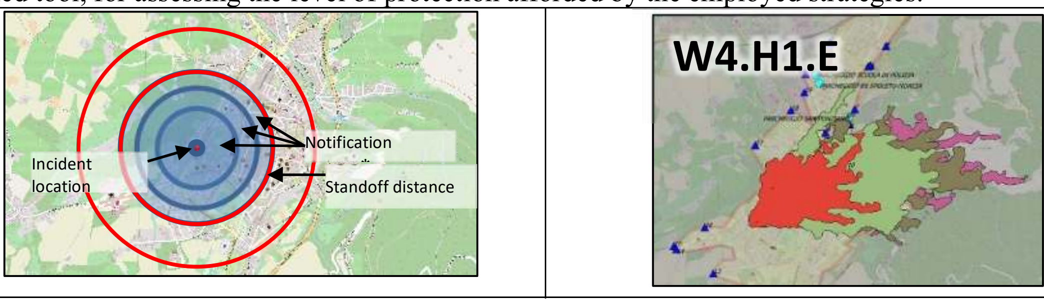

Figure 1: Standoff distance and notification sequence (Left) Hazard Spread (Right)

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Simulation of Downhill Skiing Areas

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Safety and comfort are important demands for downhill skiing areas. High densities of skiers on ski slopes reduce comfort and lead to an increasing risk of accidents through collisions. In cooperation with the KFV (Kuratorium für Verkehrssicherheit) [1] in Austria we investigate the influence of various factors on the safety of skiers, e.g. the density, the experience of skiers etc. We consider skiing as two-dimensional traffic system and adapt models and concepts initially developed for pedestrian dynamics. Specifically, we propose a simple cellular automaton model that captures some essential properties of downhill skiing traffic that can be compared to empirical data (see e.g. the trajectories in Fig. 1).

Previous modeling approaches were based on the Social-Force Model [2,3]. This allows to consider forces due to hill topology in a very detailed way. Cellular automata, on the other hand, are based on stochastic dynamic rules which reflect the decision on speed and direction of the skiers. This allows to easily incorporate other effects, like emotional states, wish for comfort and safety etc. which would be difficult to capture by forces.

The model can be extended to make it more realistic by including other relevant aspects. One important extension concerns anticipatory behavior for collision avoidance. Furthermore, the effects of an inhomogeneous population of skiers are studied, especially skiers with different skills. Other aspects of practical relevance are the inclusion of boundaries of the skiing areas, topology of the area and the effect of bottlenecks.

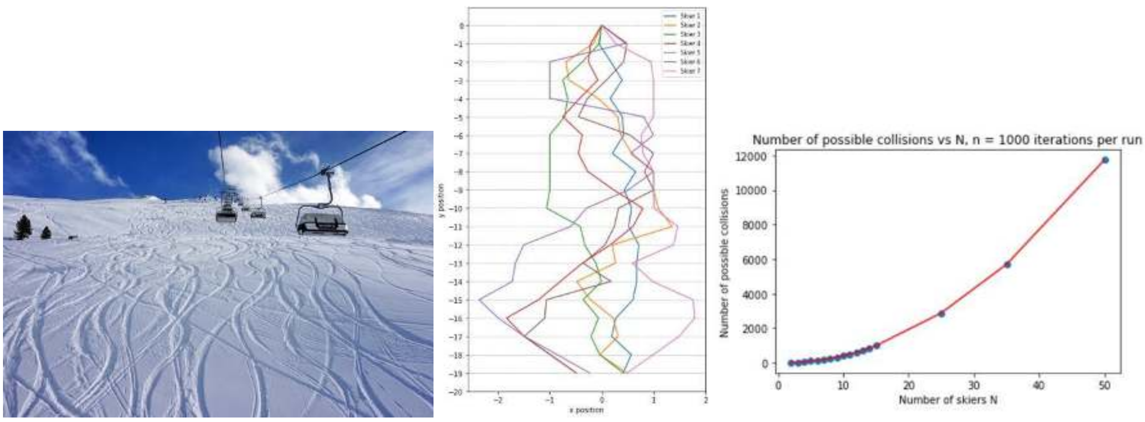

Figure 1: Real vs. simulated trajectories of downhill skiers (left, middle); Number of collisions as function of the density of skiers (right)

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
Eindhoven, The Netherlands – June 28-30, 2023

Influence of groups of different gender composition in single-file experiments

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Various studies deal with the question of which factors are relevant for the course of the fundamental diagram in single-file experiments. Some indicate that there are differences due to group composition when gender is considered. Subaih et al. [1] have shown that for densities higher than 1.0 m^{-1} homogeneous gender compositions lead to higher speeds than a heterogeneous composition with an alternating order. In Paetzke et al. [2] it was concluded that the human factor gender could be neglected. For this reason, further single-file experiments with homogeneous and heterogeneous group compositions were conducted. To investigate whether there are differences between the mean of velocity in different density ranges a Tukey HSD test is performed. The comparison of different group compositions shows that the influence of gender, if at all, appears only in a small density interval. In addition, regression analyses are conducted to analyze whether, at high densities, the distance between individuals depends on the gender of the neighboring pedestrians and to investigate which human factors have an effect on the velocity. The investigation of the distances between individuals at high densities indicates that there is no influence of gender of the neighboring pedestrians. The consideration of additional human factors in a regression analysis does not improve the model. Figure 1 shows a density vs. velocity fundamental diagram for the single-file experiments at the Mitsubishi Electric Halle in Düsseldorf, Germany in 2021 [3] up to a density of 2.5 m^{-1}.

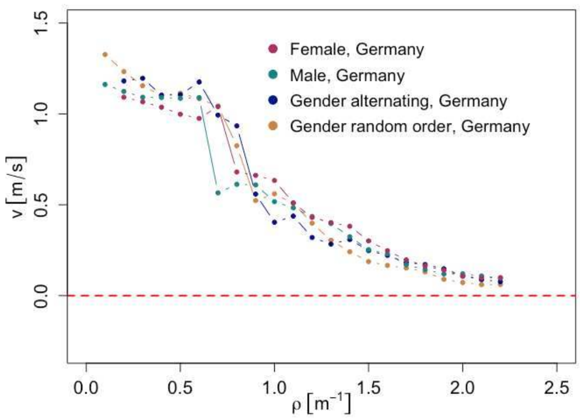

Figure 1: Density vs. velocity fundamental diagram for single-file experiments with binned data of the mean values of the velocity for groups of different gender compositions.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Ground Pressure Sensors for Privacy-aware Crowd Counting

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Counting the number of people in a public event is an essential task for a number of social domains, including urban planning, population health, and public safety. Traditionally, computer vision has played a central role in such counting tasks, but the issue of privacy has been raised from the ethical perspective of unconsented data collection in public spaces. Therefore, there is a growing need for a method that balances both privacy and performance. In this study, a privacy-aware crowd counting method based on ground-based pressure sensing is proposed. This method uses a pressure sensor array integrated into the ground surface of a public space to measure the spatio-temporal change in pressure distribution [1]. In addition, a large-scale ground pressure dataset has been constructed and made available to the research community. In principle, it is possible to count people with reasonable accuracy just from the pressure data information, without collecting privacy invasive data such as facial images, as camera-based methods do. To build a dataset, prototype pressure sensors were placed on the ground at the entrance gate of a public fireworks display and captured the gait patterns of over 1,500 pedestrians. LiDAR measurements were also included in the dataset as complementary ground truth to properly evaluate the ground pressure-based method. In addition, a baseline crowd counting method called the Trajectory Moment Method is proposed, where the algorithm is specifically designed to be sensitive and robust to pedestrian behavior. As a result, the model achieves 98 % accuracy in the proposed dataset, suggesting the effectiveness of the ground-integrated measurement method as a promising option for future privacy-aware crowd counting.

In future research, we aim to use ground pressure sensors for traditional crowd analysis tasks that have typically been addressed using vision-based methods, such as navigating pedestrians with obstacle situations [2], analyzing bidirectional traffic flow [3], and estimating relationships in a social group [4]. We believe that the integration of advanced sensing and analysis technologies into an intelligently augmented architecture will result in a more aware and responsive physical environment that can provide real-time feedback and support long-term urban planning.

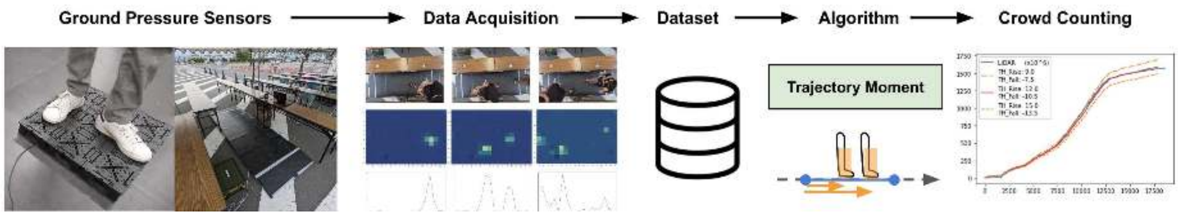

Figure 1: Complete pipeline for privacy-aware crowd counting using ground pressure sensors: This study (1) deployed ground pressure sensors in a public event with over 1,500+ passersby; (2) captured a time series of high resolution pressure images for 300+ minutes; (3) constructed a dataset in combination with the ground truth counting data obtained off-the-shelf crowd counter; (4) proposed a baseline analysis method for privacy-aware crowd counting; and (5) achieved the counting result of 98 % accuracy.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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A virtual experimental study of circle antipode experiments based on the characteristics of brain functional connection

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Understanding pedestrian evacuation behaviour in emergencies is the key to the management and control at assembly occupancies. In fact, pedestrian evacuation behaviour in emergency is a complex dynamic process, which not only stimulates the "fight or flight" response in behaviour [1], but also produces obvious psychological and physiological reactions [2-4]. The high objectivity of individuals' physiological activity presents a challenge for quantitative and accurate study on pedestrians' psychological and physiological reactions in dangerous situations. Immersive virtual environments provide a platform for studying human behaviour [5,6]. Once participants experience a high level of presence in the virtual environment, they will have real physical and psychological reactions. Especially human brain is the most important central nervous system of individuals, which profoundly affects people's psychology, decision-making and behaviour. Therefore, this paper performs a virtual experimental study of circle antipode experiments and explores the relationship between test subject's brain functional connection and route choice.

Figure 1: Schematic of experimental settings.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Evacuation from Cramped Interiors with Aisle Seats: Uncertainty Induced by the Random Choice of Initial Positions

Juraj Kmec[1], Pavel Hrabák[1], Hana Najmanová[1], and Daniel Vašata[1]

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Cramped interior layouts (such as lecture and theatre halls, stadium sectors, or public transport vehicles) are typically characterized by narrow aisles, merging streams, and seat rows limiting the overtaking of occupants. The combination of these factors implies specific evacuation dynamics and pathfinding of the occupants, which is strongly impacted notably by a fixed set of their initial positions/seats.

This contribution presents a simulation study which explores the uncertainty caused by a variation of initial seating positions determined by artificial energy values. The presented results lean over previous work focused on railcar evacuation analysis [1, 2] and develop the finding indicated that the uncertainty in measured total evacuation times (TET) caused by variation in initial seating positions is comparable to uncertainty induced by other sources of randomness. In addition to railcar simulations, this paper also introduces a case study of a lecture room with a capacity of 74 seats. In both cases, a series of simulations using the Pathfinder model was performed to capture different conditions of 75%, 90% and 100% occupied layout capacity. To investigate the influence of crowd heterogeneity, two agent types with different movement abilities were established: Without limitation (average healthy adult pedestrians) and With limitations (pedestrians limited by lower speeds or accelerations). A homogeneous reference group (HOM) was composed only of Without limitation agents; a heterogeneous group (HET) consisted of both types of agents. The effect of the initial conditions was quantified using the artificial energy values $E(C)$ assigned to individual combinations of seating positions C. The energy $E(C)$ was calculated as a superposition of potentials of imaginary forces acting on a hypothetical pedestrian choosing a seat during ingress processes (such as inter-agent repulsion or attraction towards an exit). Different weights of considered energies were used for each agent type to quantify seating variations among the HET group.

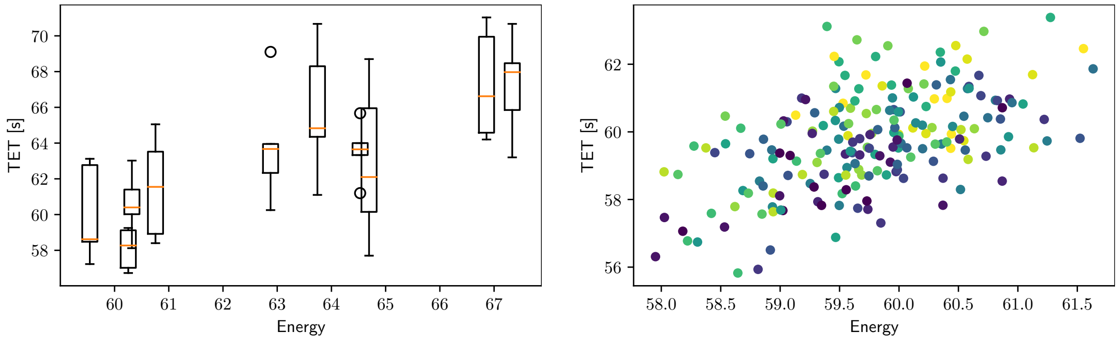

Figure 1: TET depending on the energy of initial seating. Left: HOM, railcar, 90% of capacity. Right: HET, lecture hall, 75% of capacity. Points of one color correspond to the same set of occupied seats differing by the positions of agents With limitation.

In the left part of Fig. 1, a box plot of TETs for the homogeneous agent group (HOM) shows an almost linearly increasing average TET with respect to the seating energy. In the right part of Fig. 1, this linear-like increase of TET can be seen more clearly in the heterogeneous agent group (HET), specifically even among initial positions differing only in positions of disabled agents (With limitations). These results indicate that the variance in seating energy can help explain an overall variance of TET and show the importance of ingress studies in evacuation experiments with cramped interiors. In addition, the ability to evaluate seating positions using energy may help design relevant simulations and experiments.

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Towards a global observatory of pedestrian flow management levers in stations

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Crowd disasters are more and more known and documented, but the ways of preventing them don't follow closely that trend. Train and station operators face an increasing pressure with pedestrian flow management, as ridership often grows more quickly than resources, and cannot rely on a pedestrian flow overview. To help tackling these issues, we launch a global observatory of the current practices and research about pedestrian flow management in stations. This observatory collects, analyses, and synthetises the available information from train and station operators, existing databases, academic and grey literature.

In the literature, some papers and books are already explaining very interesting pedestrian flow management techniques, such as [1] in Santiago del Chile, [2] in Rio de Janeiro, [3] in Lausanne, or [4] for a global introduction. As the latter, several websites are listing crowd accidents and near-miss cases, such as [5], [6], [7] and [8]. However, they generally don't analyse the causes of the accidents, and they don't offer a panorama of the levers that could be used for preventing disasters or in daily use. Moreover, flow management is not limited to safety and should also enable comfort, accessibility, or railway operation efficiency, which is not broadly covered by these sources.

To address these issues, the observatory collects and shares well-sourced information about crowd and pedestrian flow management, focusing on the case of train stations. We aim to run that observatory in an open-source and collaborative manner, involving railway companies, station managers, and researchers. One of the first tasks of the observatory is to compare existing sources for crowd accidents [6-10] using Wikidata. We will present the first findings from this investigation, and notably if major causes can be distinguished. We will also present our methodology for analysing pedestrian levers and its application on the first collated levers. Finally, we will assess the criticality of flow management in a selection of stations.


Figure 1: Visualising crowd accidents with Wikidata. Figure 2. One of analysed crowd levers, Lausanne

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11th International Conference on Pedestrian and Evacuation Dynamics (PED2023)
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Optimization of Travel Efficiency of Deeply Buried Subway Stations with Elevator Assistance

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Due to the advantages of high operating speed, good punctuality, large volume and high security, subway stations have developed rapidly and gradually become one of the main means of transportation for urban residents. Simultaneously, it is an important mode of transportation to ease urban traffic congestion. With the rapid development of the city, the deep underground personnel-intensive places are constantly constructed, and the shallow underground space is becoming more and more tight. In consideration of a variety of intricate topographic structures, most of the subway stations are mostly laid deep. With the increasing number of subway stations, the burial depth is getting deeper and deeper. Traditional stairs and escalators that can take a lot of precious travel time for passengers in deep-buried subway stations can hardly meet passengers' demand for highly efficient travel, which will greatly affect the travel satisfaction of passengers.

In order to optimize the travel efficiency of passengers in deep-buried subway stations, this paper put forward the strategy of setting up elevators in deep-buried subway stations, so that passengers can travel through the combination of elevator, escalator and stairs when entering and leaving the elevator. Firstly, for the sake of having in-depth research of the passenger travel behaviour in deep-buried subway stations, the way of questionnaire survey was adopted. The questionnaire survey used in this paper was divided into two types: Revealed Preference (RP survey) and Stated Preference (SP survey). RP survey was used to understand the actual travel behaviour of passengers in the subway stations. These behaviours include acceptance probability of elevators, the longest time passengers can stand waiting for an elevator in conventional subway stations and the longest time of taking escalators that passengers can endure during daily commuting of passengers in deep-buried subway stations, and so on. SP survey was to study the choice behaviour under the hypothetical condition. Hongtudi Station of Rail transit Line 10 in Chongqing, China, was selected as the study case for modelling and simulation analysis. According to the data of the questionnaire survey, the probability of passengers choosing the elevator, the longest time passengers can tolerate waiting for an elevator and taking the escalator were put into the simulation model. The average travel time of inbound passengers and outbound passengers were taken as the index. This paper set up several simulation scenarios, and the evacuation efficiency of passengers under different passenger flow, elevator number, speed, capacity, elevator stop location and other factors were studied. The optimal setting of elevator parameters under different passenger flows was found. With these parameters, the travel efficiency of passengers in the deep-buried subway station was greatly improved.

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