Age and Group-driven Pedestrian Behaviour: from Observations to Simulations

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Age and Group-driven Pedestrian Behaviour: from Observations to Simulations

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Abstract The development of pedestrian simulation systems requires the acquisition of empirical evidences about human behaviour for sake of model validation. In this framework, the paper presents the results of an on field observation of pedestrian behaviour in an urban crowded walkway. The research was aimed at testing the potentially combined effect of ageing and grouping on speed and proxemic behaviour. In particular, we focused on dyads, as the most frequent type of groups in the observed scenario. Results showed that in situation of irregular flows elderly pedestrians walked the 40% slower than adults, due to locomotion skill decline. Dyads walked the 30% slower than singles, due to the need to maintain spatial cohesion to communicate (proxemics). Results contributed to refine the parametric validation of the agent-based simulation system ELIAS38.

Keywords Pedestrian · observation · simulation · ageing · groups · proxemics

1 Introduction

Progressive urbanisation is one of the most significant global tendencies [1]: by 2025 the 58% of the world population will live in cities and large urban agglomerates. The issue of developing urban sustainable transportation strategies is becoming a mandatory requirement for municipalities to enhance the quality of life of the citizens.

Facing this trend, advanced urban planning activities are shifting toward a focus on *walkability*, namely how conducive and friendly the urban environment is for walking (e.g., street connectivity, access to buildings and transit facilities, quality of sidewalks, safety of pedestrian crossings) [2]. The European Charter of Pedestrians' Rights[1] (1988) highlighted the need to ensure the comfort and safety of pedestrians in urban areas, including the elderlies and people with impaired mobility (*pedestrian-friendly cities*).

> European Charter of Pedestrians' Rights (1988), Art. No.1: "*The pedestrian has the right to live in a healthy environment and freely to enjoy the amenities offered by public areas under conditions that adequately safeguard his/her physical and psychological well-being*".

Within this scenario, the role of advanced computer-based systems for the simulation of the dynamical behaviour of pedestrians is becoming a consolidated and successful field of research and application, thanks to the possibility to test the efficiency, comfort and safety of alternative spatial layouts for pedestrians.

In particular, simulations allow to import a digital representation of a determined facility (e.g., CAD files) and to populate it with a certain number of agents, which navigate the environment according to a set of behavioural rules and individual goals/preferences. Then, a series of analyses on simulation results can be performed to evaluate key performance indicators (e.g., travel time, perceived density, waiting time). Of course, the digital representation of the environment can be easily changed, according to different planning hypotheses aimed at exploring potential ways to improve the situation and support the walkability assessment.

The development of simulation systems requires a cross-disciplinary methodology (e.g., computer science, social science, urban planning) in order to calibrate and validate the model itself and the related simulation results by means of empirical studies about pedestrian dynamics. In this framework, this paper introduces the results of an on field observation focused on age and group-driven pedestrian behaviour in urban contexts, for sake of model and simulation validation. In particular, we tested the potentially combined impact of ageing (progressive decline of locomotion skills) and grouping (need of group members to maintain spatial cohesion to communicate) on speed. We will further elaborate these points in Sec. 1.1 and Sec. 1.2.

A video-recorded observation was performed in a crowded touristic-commercial walkway in Milan (Italy): the Vittorio Emanuele II gallery. A preliminary study about the pedestrian dynamics observed at the gallery has been already presented by the authors [3]. Results showed that the granulometric distribution of pedestrians was characterised by the massive presence of two-members groups (dyads), which were the 44% of the total pedestrian flows. Starting from these preliminary findings, the current work is based on a more recent and accurate data analysis campaign, based on the usage of an open source tracking tool. In particular, this change in the instrument used by annotators granted the possibility to provide smooth and continuous trajectories instead of discrete positions on a 40 cm sided cells of a grid superimposed on the video frames. Moreover, we extended the number of tracked pedestrians by sampling adult and elderly pedestrians (aged pedestrians were not considered in the previous analysis), singletons and walking dyads.

[1] See `http://goo.gl/7J8xij`

The adopted methodology is presented in Sec. 2. The case study is presented in Sec. 3, with emphasis on data analysis and results about trajectories, speed and group proxemic behaviour. The paper concludes with remarks about results and their use for the validation of the simulation system ELIAS38 [4, 5], with reference to the representation of different granulometric distributions of groups, heterogeneous speed profiles and group cohesion mechanism (Sec. 4).

1.1 Age-driven Pedestrian behaviour

The concept of *Age-friendly Cities*, introduced by the World Health Organisation [6], describes a framework for the development of cities which encourages the active ageing of the citizens. This consists of guidelines and policies for assessing and increasing the accessibility of urban facilities for the elderly. The mobility of aged people represents indeed a key factor for supporting them in maintaining an active and productive status, in spite of the progressive social isolation linked to ageing [7].

Compared to adult pedestrians, elderlies are characterised by limitations in locomotion behaviour, such as lower speed and higher stress response to density [8]. This is strongly conditioned by the progressive decline in the operation of: (*i*) perceptive sensors (e.g., limited perception of light and colours, inability to tune out background noise) and (*ii*) locomotor-cognitive skills (e.g., reduced range of motion, loss of muscle strength and coordination, changes in posture, diminished attention and reaction time, spatial disorientation) [9]. All these bodily changes lead to a subjective perception of physical vulnerability and a sense of fragility at the psychological level [10]. This is the reason why elderly people are more provident in the space, and they move more slowly keeping more space around themselves.

1.2 Group-driven Pedestrian behaviour

Recent empirical contributions [11, 12] clearly showed that pedestrian flows in urban crowded scenarios are characterised by the preponderant presence of groups: social units featured by common goals and variable strength of membership. In particular, the granulometric distribution of pedestrian flows is strongly affected by two-members groups (*dyads*), which represent the most frequent and basic interacting elements of crowds [3].

This phenomenon is largely determined by the motivation by which people are gathered or move through a certain environment, and/or by the type of event they are participating to (*crowd profiling*) [13]. For example, transportation facilities are mainly characterised by the presence of fast moving single commuters, while other collective venues are more often characterised by the presence of informal and/or structured groups of visitors, generally moving slower than the former type of pedestrian.

Analyses of pedestrian dynamics not considering this aspect have a reduced accuracy since grouping was found to negatively impact speed, flow rate and evacuation time [14]. In particular, elements such as the level of density, the presence of obstacles and the geometry of the environment, can create difficulties in movement coordination among group members, depending on: the need to maintain spatial cohesion to communicate

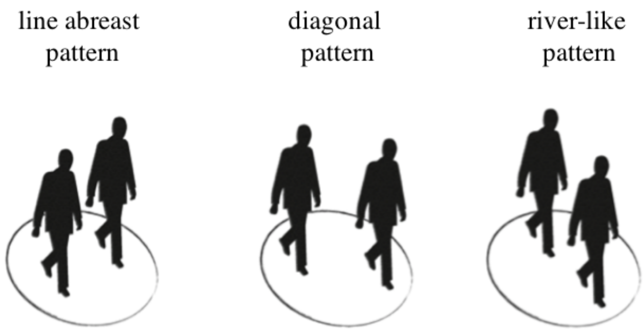


Figure 1 The typical spatial patterns of walking dyads: line abreast, diagonal and rive-like patterns.

while walking (*proxemic behaviour*) [15] and/or the urgency to evacuate together in case of emergency (*affiliative behaviour*) [16].

In particular, group proxemic behaviour while walking is characterised by the dynamic regulation of interpersonal distances between members and by different spatial patterns [15]: at low density dyads members walk side by side (*line abreast pattern*), but, when the density increases, the linear formation turns into a *diagonal pattern* with an individual positioned slightly behind in comparison to the other one. In situation of high density, dyad members leads to a *river-like pattern* to minimise collisions with other pedestrians (see Fig. 1). Thus, irregular conditions of density generate turbulences in the walking behaviour of dyads in terms of the dynamic regulation of interpersonal distances and spatial patterns, with detriment of speed.

2 Methodology

The methodology is based on the integration between data collection techniques focused on locomotion behaviour (*analysis*) and the power of computer-based pedestrian simulations (*synthesis*) [17]. The results obtained from the observation of pedestrian behaviour give the basis for the validation of computer-based simulation systems, testing the adherence of the simulation results on realistic behavioural dynamics.

2.1 In Vivo Observation

On field observations [18], *in vivo* from Latin "living", allow to unobtrusively collect empirical data about pedestrians' behaviour (subjects are not aware to be observed, the observer does not intrude the stage), considering the physical and social features of the environment in which the subjects are situated. The main difference between experiments performed in controlled laboratory settings and observations is the possibility to exert a limited amount of control over the environment in which the empirical study takes place, but also the higher possibility to generalise results (ecological validity) [19].

The design of observations requires to systematically consider several practical elements (e.g., scenario, duration time of the survey, staff members, professional equipment for data collection, authorisation to carry out the survey, ethical restrictions). In particular, the issue about the privacy of the people participating the study represents a crucial aspect, due to the difficulty to obtain their informed consent beforehand [20].

The data collected by means of the observation (e.g., notes, video images) are analysed focusing on the occurrence and modalities of specific pedestrian behavioural indicators (e.g., levels of density, trajectories, speeds, pedestrian profiles and habits). Finally, it is highly recommended to cross-check results by means of two or more observers, who analyse data by using a shared taxonomy for the definition of the observed phenomenon.

2.2 In Silico Simulation

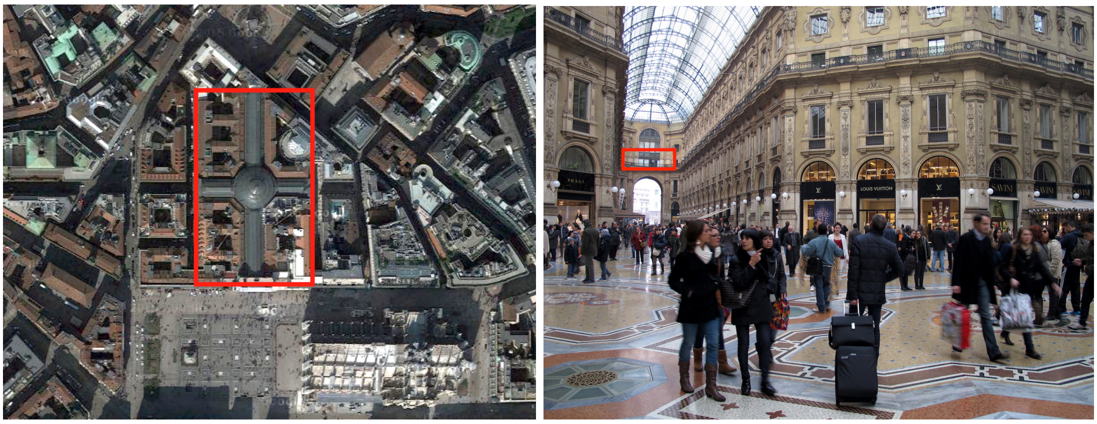
Although there are some objections about the simplified level of correspondence between computer-based simulations and complex social systems [21], this methodology, *in silico* (on the computer), allows to envision those phenomena that are difficult to be directly observed in real scenarios, testing alternative conditions and courses of action (*what-if scenarios*). The issue of defining computational models about pedestrian dynamics has been tackled from different perspectives:

- *Physical* approach [22] represents pedestrians as particles subject to forces (e.g, attraction and repulsive forces), in analogy with fluid dynamics;
- *Cellular Automata* approach [23] represents pedestrians as occupied states of the cells. Pedestrian interactions are based on the *floor field* method: a virtual trace that influences pedestrian transitions and movements;
- *Agent-based* approach [24] represents pedestrians as heterogeneous, autonomous and situated entities moving according to behavioural rules and specifications.

ELIAS38 is an agent-based simulation system and its core computational model allows the explicit representation of groups of agents, interacting through proxemics rules (need to maintain spatial cohesion during locomotion) [25]. In particular, agents have the capability to: perceive and avoid obstacles, follow paths, perceive other agents, achieve individual and/or shared goals. The ongoing validation process of the simulation platform is aimed at refining the representation of different granulometric distributions of groups, heterogeneous speed profiles and group cohesion mechanism.

3 Case Study

This Section presents the results of a large data gathering campaign performed on Saturday 24$^{\text{th}}$ November 2012. The case study consisted of a video-recorded observation of pedestrian circulation dynamics at the Vittorio Emanuele II gallery (Milan, ITALY).



(a) (b)

Figure 2 The aerial of the gallery (freely taken from Google Maps) (a), and the balcony used for positioning the video camera (highlighted in red) (b).

The gallery (see Fig. 2) is an historical glazed arcade from the late 19th century, located in the city centre of Milan. The plan of the gallery is the shape of a Latin cross with its centre expanded into an octagon. It is a popular touristic-commercial walkway, exclusively intended for pedestrians (no interplaying environmental variables related to vehicular traffic). It is characterised by heterogeneous pedestrian profiles (tourists, shoppers, strollers and inhabitants) and group granulometric distribution [3].

An HD camera was located on the balcony inside the volume of the gallery at an height of 19 meters (see Fig. 2), and with a nearly zenith perspective in order to limit trajectories occlusion. The railing of the balcony allowed to not influence the behaviour of pedestrians by partly hiding the camera. The geometric decorated pavement of the walkway allowed to fix several spatial reference points to correct the video frames, avoiding the distortion due to the inclined perspective of the camera. The glass-vaulted arcade that covers the gallery permitted to prevent that, in case of a rainy day, the presence of umbrellas would occluded pedestrians.

3.1 Data Analysis

Data analysis was performed by using the open source software Tracker Video Analysis and Modelling Tool[2], which allowed to correct the distortion of the video images and to semi-automatically track a sample of pedestrians (see Fig. 3).

In particular, the functions *Filter Perspective* and *Filter Resize* allowed to correct the distortion of the images, maintaining the proportion of the area by adjusting the pixels. The function *Origin of the Axes* and *Calibration Stick* allowed to set the origin and dimension of the orthogonal plane. The function *Point Mass* allowed to track pedestrians one frame every ten (every 0.4 sec), considering the space in between their feet. The data set including the pedestrians' positions (X, Y) and frames (t) was exported for data analysis.

[2] See `http://www.cabrillo.edu`

Elderly Detection	
Locomotion behaviour	- regular walking pace - attentive in anticipating oncoming pedestrians by far - unsteady gait and lame posture
Physical Characteristics	- white hair/baldness - clothing (e.g., style, colours, hat) - use of artifact (e.g. stick, tripod)
Dyad Detection	
Locomotion behaviour	- high spatial cohesion and coordination while walking - waiting dynamics to regroup in case of separation - leader/follower dynamics in sudden changes of direction
Verbal behaviour	- talking while walking
Non Verbal behaviour	- physical contact - body and gaze orientation to the each other - gesticulation while talking and/or indicating

Table 1 The checklist used by the coders for identifying elderlies and dyads, considering a set of locomotion, communication and physical indicators.

No. 62 persons were tracked while walking into a delimited area of the gallery (163.84 squared meter), by taking into account only the minutes of the video characterised by irregular flows at LOS B (see Sec. 3.2). Those pedestrians who stopped or slowed down to talk, take pictures or shop were not traked. The total sample was composed of: 15 adult singles, 16 adult dyad members (8 dyads), 15 elderly singles, 16 elderly dyad members (8 dyads). The identification of elderly pedestrians (from about 65 y.o.) and dyads was supported by the use of an *ad hoc* designed checklist (see Tab. 1), comprising a set of locomotion, communication and physical indicators.

The sample was also balanced among the gender and direction of movement of pedestrians, as composed of: 60% male and 40% of female single pedestrians; 50% same gender dyads (25% male-male, 25% female-female) and 50% mixed gender dyads. The 58% of pedestrians walked from South to North (entering into the gallery), while the 42% of them walked from North to South (exiting from the gallery).

3.2 Density, Flow Rate and Level of Service

The average level of density (0.22 people/squared meter) was measured by counting the number of people who occupied the delimited area of the gallery (163.84 squared meter), considering the first frame of each minute of the video (see Fig. 4(a)). The average pedestrian flow rate (7.78 pedestrian/minute/meter) [26] was measured by counting the number of people walking through the delimited area minute by minute (see Fig. 4(b)).

Results were compared according to the Walkway Level of Service Criteria (LOS) [27] (see Tab. 2): a range of values that standardly describe the impact of contextual situations

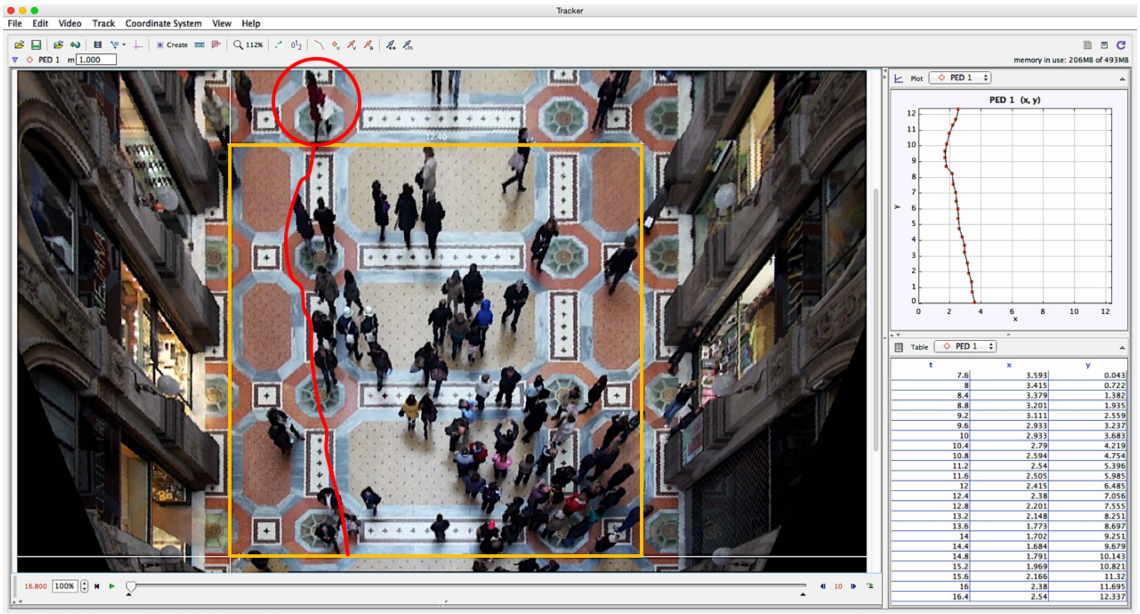
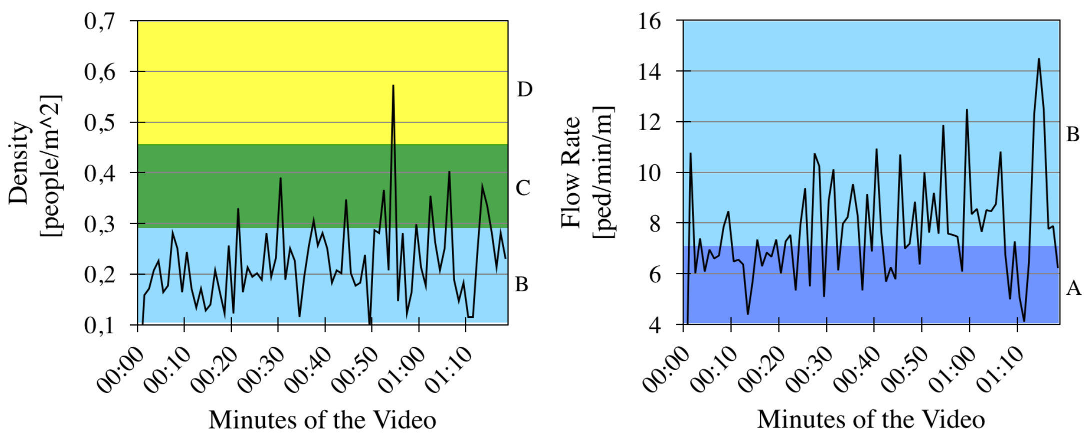


Figure 3 A screenshot of the the video analysed by using the *Tracker Video Analysis and Modelling Tool*. The images highlights the trajectory of one single pedestrian.



(a) (b)

Figure 4 Results about the level of density (a) and flow rate (b). The corresponding Level of Service are highlighted with coloured backgrounds and labels.

of density on pedestrian circulation dynamics (from LOS A-pedestrian free flow, to LOS F-extremely difficulty in walking movements). The average level of density and flow rate corresponded to LOS B, that is associated with irregular flows under low density. However, several situations of local medium-high density have been observed due to the occasional presence of large groups of tourists, but also situations in which smaller groups moving in opposite directions were situated in the same side of the walkway.

Level of Service Criteria	Level of Density *(people/squared meter)*	Pedestrian Flow Rate *(pedestrian/minute/meter)*
A - free flow	$\leq$0.08	$\leq$7
B - minor conflicts	0.08 - 0.27	7 - 23
C - slower speed	0.27 - 0.45	23 - 33
D - restricted most	0.45 - 0.69	33 - 49
E - restricted all	0.69 - 1.66	49 - 82
F - shuffling	$\geq$1.66	$\geq$82

Table 2 The Walkway Level of Service criteria [27], which standardly describe the impact of contextual situations of density on pedestrian circulation dynamics.

3.3 Trajectories and Speeds of Pedestrians

Data analysis was mainly aimed at testing the potentially combined effects of ageing and grouping on trajectories and speeds (see Fig. 5 and Tab. 3), but we focused also on the impact of gender and direction of movement of pedestrians on results.

A two-factor analysis of variance[3] (two-way ANOVA) was conducted to compare the length of trajectories of adult singles (13.01 m $\pm$ 0.56 sd), adult dyads (12.86 m $\pm$ 0.49 sd), elderly singles (12.80 m $\pm$ 0.34 sd) and elderly dyads (12.84 m $\pm$ 0.34 sd) (see Fig. 5(b)). Results showed a non significant effect for the *age* factor on trajectories [F(1,58) = 0.97, p = 0.33], as well for the *group* factor [F(1,58) = 0.25, p = 0.62].

The average length of the trajectories of adult singles was longer then the ones of adult dyads and elderly pedestrians in general. Single pedestrians were found to walk with a wavy path, overtaking slower pedestrians and avoiding spatial collision due to the local situation of density. On the contrary, dyads and elderlies were found to walk with stable trajectories, with detriment of speed (as illustrated in Fig. 5(b)). However, data analysis showed that the difference among results was not statistically significant.

A two-factor analysis of variance was conducted to compare the speed of adult singles (1.25 m/s $\pm$ 0.23 sd), adult dyads (0.88 m/s $\pm$ 0.08 sd), elderly singles (0.68 m/s $\pm$ 0.19 sd) and elderly dyads (0.61 m/s $\pm$ 0.09 sd) (see Fig. 5(a)). There was a significant effect for the *age* factor on speed [F(1,58) = 105.97, p $<$ 0.001] and also for the *group* factor [F(1,58) = 28.61, p $<$ 0.001]. Moreover, results showed that the interaction between the two factors was significant [F(1,58) = 13.58, p $<$ 0.001]. A series of post hoc independent-samples t-test (two-tails t-test, assuming equal variances) showed that the speed of elderly singles and dyads did not differ significantly, t(29) = 2.05, p = 0.21.

An independent-samples t-test showed that there was not a significant difference between the speed of single males and females, t(28)=2.05, p = 0.94. A one-factor analysis of variance showed a non significant effect of the variable gender on the speeds of dyads, compared among for the three conditions (same gender male, same gender female, mixed gender) [F(2,29) = 0.97, p = 0.39]. Moreover, an independent-samples t-test showed that the direction of movement did not significantly affect the speed of pedestrians, t(60)=2.00, p = 1.00.

[3] All the analyses presented in this work have been conducted at the p $<$ .01 level.

	Adult Singles	Adult Dyads	Elderly Singles	Elderly Dyads
Trajectories	13.01 m ± 0.56	12.86 m ± 0.49	12.80 m ± 0.34	12.84 m ± 0.34
Speed	1.25 m/s ± 0.23	0.88 m/s ± 0.08	0.68 m/s ± 0.19	0.61 m/s ± 0.09
Distance	-	0.64 m ± 0.31	-	0.65 m ± 0.20
Alignment	-	0.17 m ± 0.18	-	0.21 m ± 0.17

Table 3 Results about speed, trajectories, X and Y-distance among dyads.

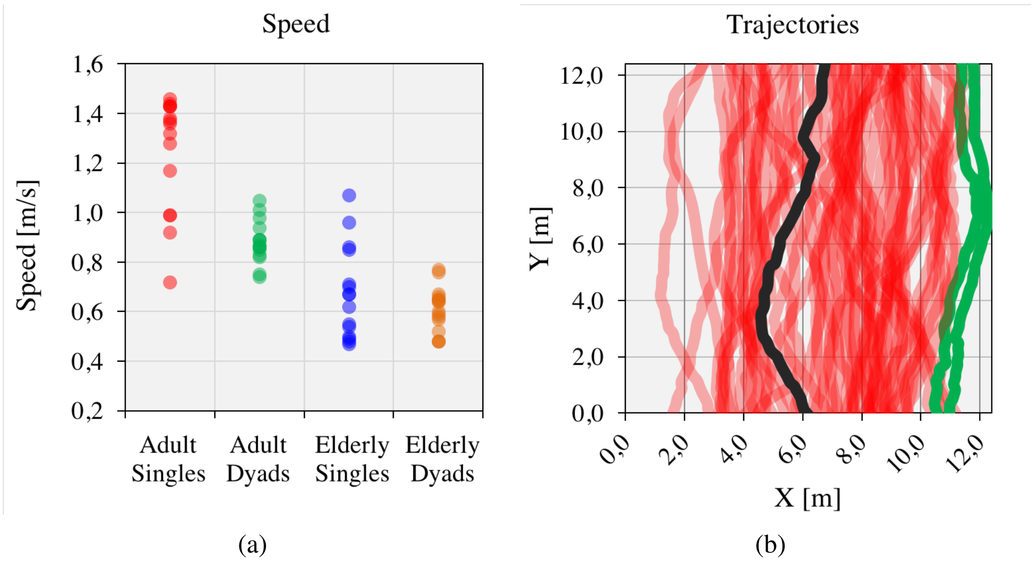


Figure 5 The speeds (a) and trajectories of pedestrians (b), plotted with a transparent effect to emphasise the distribution of results. The trajectories of one adult single and one adult dyad are highlighted with different colours.

In conclusion, results showed that elderlies (0.64 m/s ± 0.15 sd) walked in average the 40% slower than adults (1.06 m/s ± 0.25 sd), due to the decline of locomotion skills linked to ageing. Moreover, adult dyads walked 30% slower than adults singles, due to the difficulty in coordinating their movement in condition of irregular flows and the need to maintain spatial cohesion to communicate (proxemics). The speed of elderly singles and dyads did not differ significantly. Walking in pairs probably represented for the elderlies a supportive element for maintaining a regular pace in condition of irregular flows. Gender and direction of movement of pedestrians had no effect on their speeds.

3.4 Proxemic Behaviour of Dyads

Data analysis was aimed at testing the effect of density (LOS B) on group proxemic behaviour, comparing results among adult and elderly dyads. Proxemics was measured as the distance between the relative positions of dyad members and the geometrical centre of the group (centroid), calculated on the X-axis and the Y-axis (see Fig. 6 and Tab. 3).

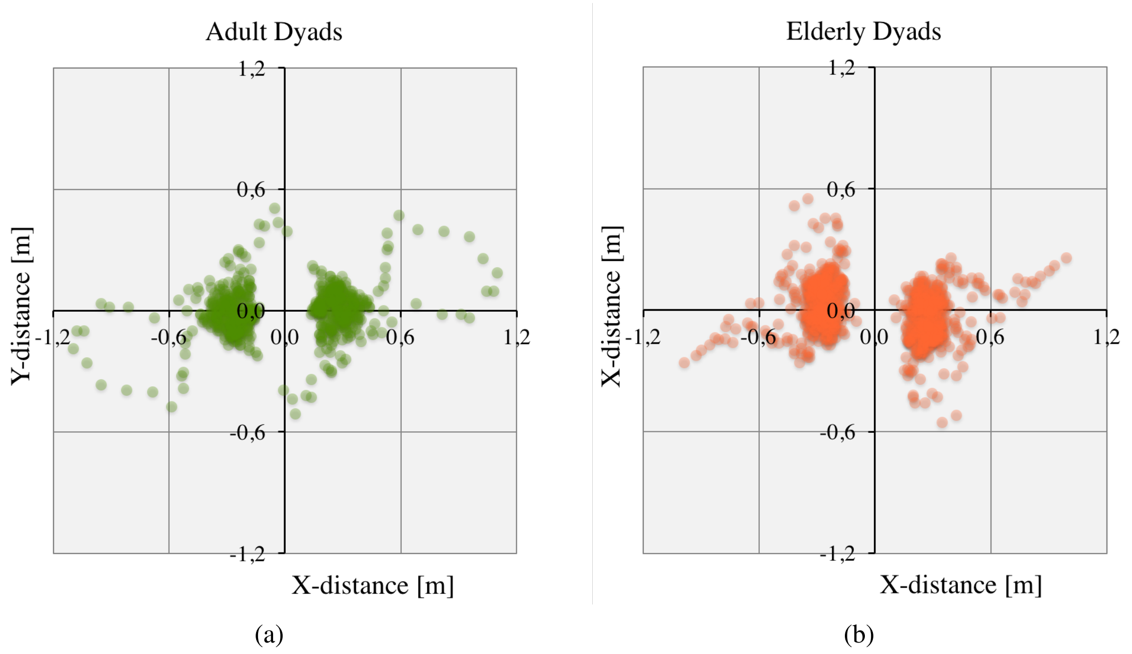


Figure 6 The relative positions of adult (a) and elderly dyads (b) with respect to the centroid of the group, plotted with a transparent effect to emphasise their distribution.

A series of independent-samples t-test showed that the X-distance of adult dyads (0.64 m $\pm$ 0.31 sd) and elderly dyads (0.65 m $\pm$ 0.25 sd) did not differ significantly, t(725) = 1.96, p = 0.75. A significant difference was found between the Y-distance of adult dyads (0.17 m $\pm$ 0.18 sd) and elderly dyads (0.21 m $\pm$ 0.17 sd), t(725) = 1.96, $p < 0.01$.

A linear regression was conducted to test the effect of speed on the distance of dyads members on the Y-axis. There was not a significant impact for the adult dyads [F(1,287) = 0.69, p = 0.41], but a slight significant effect was found among the elderly dyads [F(1,287) = 5.97, $p < 0.05$]. Results showed that faster elderly dyads walked less aligned than slower ones.

A one-way ANOVA showed a non significant effect of gender group proxemics for the three conditions (same gender male, same gender female, mixed gender), considering both the X-distance [F(2,726) = 0.62, p = 0.54] and Y-distance [F(2,726) = 1.08, p = 0.34].

The proxemic pattern of dyads (see Fig. 6) was estimated by aggregating the relative positions of group members, normalised with respect to the centroid of the group and the direction of movement (the positions of pedestrians walking from North to South were rotated of 180 angle degrees). Results showed that adult dyads walked side by side with a line abreast pattern, while elderly dyads walked less aligned with a slight diagonal pattern.

In conclusion, results showed that adult and elderly dyads walked with an average X-distance of 0.65 m ($\pm$ 0.27 sd), maintaining the proper spatial cohesion to communicate. Elderly dyads walked less aligned than adult ones, with a slight diagonal pattern, due to the difficulty in coordinating the speeds and movements of group members in condition local situation of density. Gender had no effect on the proxemic behavior of dyads.

4 Conclusions and Future Works

The paper presented the results of an on field observation performed in an urban crowded walkway, which was aimed at measuring the potentially combined impact of ageing and grouping on pedestrian behaviour.

Results showed that, in situation of irregular flows, elderlies walked the 40% slower than adults due to the decrement of locomotion skills linked to ageing. Dyads walked the 30% slower than singles, due to the need to maintain spatial cohesion to communicate. The negative impact of group social interaction on speed is confirmed also by the lower variability among the speeds of dyads compared to singletons (see standard deviation values in Tab. 3).

Moreover, elderly dyads were found to walk less aligned than adult dyads, due to the difficult in coordinating their movements and speeds in condition of irregular flows. In conclusion, results clearly showed the impact of age and group social interaction on pedestrian behaviour in terms of speed and proxemic behaviour.

Although several empirical studies have been performed in this framework [28, 29], there is still a lack of contributions in the design of standardised methodology for the observation of pedestrian behaviour in urban contexts. This methodology allows a limited control over the environment in which the empirical study takes place, but it allows to collect empirical data considering both quantitative measurement about human behaviour and qualitative annotations about pedestrian habits in the context of the observation.

According to this approach, we propose hereby a general conceptualisation of different walking behaviours based on this experience:

- *Time driven pedestrians*: people who have time constraints and walk through a certain environment constantly adjusting the trajectory between origin and destination to preserve a high speed (very often singles and commuters accessing public transport services);
- *Space driven pedestrians*: tourists or shoppers who visit for the first time a certain environment or have an exploratory attitude. Sometimes they are organized in large groups led by a guide. They stop more often, either for taking pictures of interesting spots or for shopping;
- *Social driven pedestrians*: strollers and inhabitants who amble thought a certain environment since they live or work nearby the area (more often small groups or families). They can stop their walk for an improvised conversation with somebody they know or for looking at the shop windows.

The presented case study was aimed at supporting the validation of the pedestrian simulation system ELIAS38 [25]. At this stage, the tool has been already used for the simulation of real case scenarios, supporting the design of practical solutions for managing pedestrian circulation dynamics in urban crowded facilities (e.g., designing the spatial layout of organised queue areas, sizing the physical layout of walkways and egress routes).

The results achieved by means of several simulation campaigns showed that the computational model is consistent with the collected empirical data (e.g., trajectories and collision avoidance dynamics, group-driven heterogeneous speed profiles, spatial cohesion mechanism among group members).

In particular, the model was able to reproduce results similar to adult singles speeds, but it showed a decrease in the velocity of elderlies and dyad members lower than the observed one. However, the achieved results must be evaluated considering the adopted model configuration: all the agents have the same desired speed (1.30 m/s). This is based on the empirically observed velocity of pedestrians traveling for business purpose in an airport terminal [29], which is different from the leisure scenario observed at the gallery.

The results of the presented empirical study will be used to refine the parametric calibration of the model, focusing on those situations in which the simulation results are not actually in good agreement with the observed age and group-driven heterogeneous speeds. Then, in a circular process, further on field observations of pedestrian dynamics will be designed and executed under a variety of circumstances, for sake of model validation.

In conclusion, the results of this study could be of notable interest for those attempting to properly model and simulate pedestrian dynamics. Simulation results are finally aimed at assessing and improving the walkability of urban facilities, supporting decision makers and planners in guaranteeing the comfort and safety of pedestrians considering also those with limited mobility, such as the elderly.

Future research activities will be aimed at: (*i*) employing the checklist used for data analysis (see Tab. 1) towards the development of automated tracking tools employing computer vision techniques [30, 31]; (*ii*) supporting a substantial improvement of the computational model of ELIAS38 [32], representing deliberative entities, characterised by more complex strategic and tactical reasoning skills and way-finding capabilities.

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