Walkability Assessment for the Elderly Through Simulations: The LONGEVICITY Project

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Abstract. In the context of global progressive urbanization and ageing of the population, the LONGEVICITY Project has the objective to study advanced solutions to assess and enhance the walkability of urban environments. This is aimed at sustaining the social inclusion of the elderly citizens. The paper introduces one of the research activities of the project, focused on the design of innovative agent-based model for the simulation of pedestrian circulation dynamics and street crossing behavior for the assessment of the level of walkability of the City of Milan (Italy). This is based on the possibility to model age-driven pedestrian dynamics while crossing as characterized by heterogeneous behaviors in terms of speeds and crossing decision. This is aimed at providing applicative design solutions to enhance the level of comfort and safety of the elderly while walking through the city and to sustain their active ageing.

Keywords: Modeling · Simulation · Ageing · Walkability

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1 Introduction

In the context of progressive urbanization [14] and population ageing [17] global trends, the project "LONGEVICITY - Social Inclusion for the Elderly through Walkability" has the objective to study advanced solutions to sustain the social inclusion of the elderly in urban contexts by enhancing their pedestrian mobility. According to the Age-friendly City framework [15], the project aims at developing innovative strategies to sustain the active ageing of the citizens by enhancing the walkability [16] of the City of Milan (Italy), with reference to the level of usefulness, comfort, safety, attractiveness and accessibility of urban environments.

The LONGEVICITY project is based on a strongly cross-disciplinary research approach, integrating skills, methodologies and tools ranging from Social Sciences, Design of Services, Artificial Intelligence and Complex Systems Science. The international team that will carry out the project is composed by four main partners: University of Milano-Bicocca, Politecnico di Milano, Research Center for Advanced Science and Technology, AUSER Volontariato Lombardia.

The research plan of the project is composed of several work packages, which aims at: (i) assessing the level of walkability of the City of Milan (Italy) through advanced GIS analyses; (ii) setting up of the living labs where to execute a series of outdoor and indoor activities participated by a large sample of elderly citizens (e.g., walking groups, participatory design activities); (iii) empirically investigating age-driven pedestrian mobility through questionnaires, field observations, controlled experiments, mobile app for smart-phones and simulations.

In particular, the paper introduces one of the research activities of the project, focused on the design of innovative agent-based model for the simulation of pedestrian circulation dynamics for the assessment of the level of walkability of the City of Milan (Italy). This is based on the possibility to model age-driven pedestrian dynamics as characterized by heterogeneous behaviors in terms of speeds and crossing behaviour. Recent empirical contributions already presented by the authors [13, 12] have highlighted the heterogeneity of both walking and crossing behavior of adult and elderly pedestrians, due to the decline of motor and perceptual capabilities linked to ageing. In particular, aged pedestrians are characterized by lower speed while walking and a higher exposure to risks while crossing.

To this end, the project is based on methodological and computational tools aimed at achieving solutions considering the needs and perceptions of senior citizens with respect to infrastructures and mobility services in the City of Milan. This is aimed at providing applicative design solutions to enhance the level of comfort and safety of the elderly while walking through the city and to sustain their active ageing.

2 Related Works on Walkability Assessment

The walkability assessment of urban areas embraces different types of knowledge and skills, within a multi-disciplinary approach [3] (e.g., urban studies, architecture, environmental psychology, computer science). Nowadays, the contributions present in literature about this topic offer a robust theoretical/methodological framework for the evaluation of the pedestrian friendliness of urban areas, in terms of *methods* for the analysis of *data* to evaluate a series of walkability *criteria*.

For what concerns the criteria, Jeff Speck [16] has recently proposed a *General Theory of Walkabaility*, which includes the following set of indicators: (*i*) presence of services within a walkable distance; (*ii*) level of comfort and safety experienced by people while walking; (*iii*) attractiveness of the urban areas in terms of architectural design and social context. The data enabling the assessment of walkability of a urban area include:

- *structured data*, related to its topographical, cadastral, infrastructural and architectural elements (e.g., presence of public services, quality of road in-

frastructures, census indicators of the socio-demographical characteristics of the inhabitants);
- *behavioral data*, related to how the spatial features of the area influences the actual behaviors of pedestrians (e.g., problematic level of services due to high density, pedestrian exposure to road accidents);
- *subjective data*, focused on the bottom up evaluations of the citizens about the level of walkability of the area (e.g., perceived level of comfort and safety).

The methodologies and techniques developed and applied to empirically measure the level of walkability of urban environments include: field observations [13, 12], audit tools [9], GIS-analysis [18, 11], web-based applications [8], social media data mining [4], computer-based simulations [1, 6, 10]. In particular, the usage of validated microscopic agent-based simulation models allows to represent age-driven pedestrian dynamics as characterized by heterogeneous behaviors in terms of speeds and other choices related to movement behaviors. This is aimed at providing applicative and optimized architectural and design solutions to enhance the level of comfort and safety of urban indoor/outdoor infrastructures.

3 Empirical Results

A video-recorded observation was performed in 2015 at an urban unsignalized intersection in the city of Milan (ITALY). The chosen scenario was characterized by a significant presence of elderly inhabitants and an high number of pedestrian/car accidents involving elderlies pedestrians in the past years.

A HD ultra wide lens camera was mounted on a light stand tripod overhung from the balcony of a private flat in correspondence of the zebra crossing. Data analysis was based on the use of the open source software Tracker Video Analysis and Modelling Tool, which allowed to correct the distortion of the video images, and then to semi-automatically track a sample of 50 pedestrians and 79 vehicles while interacting at the zebra crossing, considering one frame every ten (every 0.4 sec). Data analysis was aimed at comparing the speeds of pedestrians while crossing and the safety gap accepted by pedestrians to cross, comparing data among adults and elderlies.

A sample of 50 pedestrians and 79 vehicles was considered for data analysis. The sample was selected avoiding situations such as: platooning of vehicles on the roadway inhibiting a crossing episode, the joining of pedestrians already crossing, and in general situations influencing the direct interaction between the pedestrians and the drivers. Part of the selected crossing episodes was characterised by the multiple interaction between the crossing pedestrian and two vehicles oncoming from the near and the far lane. Considering the effects of several interfering variables on results, the sample has been designed as follows:

- Age: 27 adult and 23 elderly crossing pedestrians;
- Direction: 27 pedestrians toward point B; 23 pedestrians toward point A;
- Gender: 22 males, 28 females;
- Lane: 50 vehicles from the near lanes, 29 vehicles from the far lane;

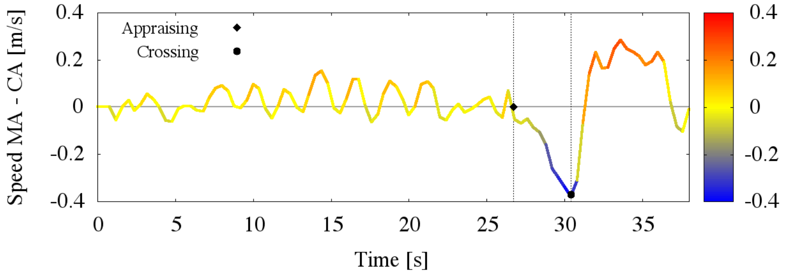

Fig. 1. An exemplification of the trend analysis performed on the time series of speeds.

- Vehicle typologies: 77 cars, 1 motorbike, 1 bus.

Pedestrian speeds have been analyzed among the time series of video frames (trend analysis), as characterized by: (i) a stable trend on side-walks, (ii) a significant deceleration in proximity of the cross-walk (decision making) and (iii) an acceleration on the zebra crossing. The trend of speeds was analyzed by calculating the difference between: the moving average (MA, time period length: 0.8 s, three frames), and the cumulative average (CA) of the entire frames series. This allowed to smooth out short-term fluctuations of data (intrinsically due to pedestrian gait, but also caused by the frame discretization) and to highlight longer-term trends (deceleration/acceleration). According to results, crossing behaviour is defined as composed of three distinctive phases (see Figure 1):

1. Approaching: the pedestrian travels on the side-walk with a stable speed (Speed MA - CA $\simeq 0$);
2. Appraising: the pedestrian approaching the cross-walk decelerates to evaluate the distance and speed of oncoming vehicles (safety gap). We decided to consider that this phase starts with the first value of a long-term deceleration trend (Speed MA - CA < 0);
3. Crossing: the pedestrian decides to cross and speed up. The crossing phase starts from the frame after the one with the lowest value of speed before a long-term acceleration trend (Speed min).

A two-factors analysis of variance[3] (two-way ANOVA) showed a significant difference among the speeds of pedestrians while approaching, appraising and crossing [F(2,144) = 61.944, p = .000], and a significant effect of pedestrian' age on results [F(1,144) = 63.751, p = .000] (see Tab. 1). A series of post hoc Tukey test showed a non significant difference between the speeds of pedestrians while approaching and crossing, considering both adults and elderlies ($p > .05$). The difference between the speed of adults and elderlies was significant among all the three crossing phases (p = .000).

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[3] All statistics have been conducted at the $p < .01$ level.

Table 1. The speed of adult and elderly pedestrians among the crossing phases.

Speed and Crossing Phases	Adults	Elderly
Approaching speed	1.28 m/s ± .18 sd	1.03 m/s ± .18 sd
Appraising speed	.94 m/s ± .21 sd	.69 m/s ± .23 sd
Crossing speed	1.35 m/s ± .18 sd	1.09 m/s ± .17 sd

In conclusion, results demonstrated that pedestrians' crossing decision is based on a significant deceleration in proximity of the curb (appraising) to evaluate the distance and speed of oncoming vehicles. Elderly walked in average 22% slower than adults among the three crossing phases, decelerating 6% more than adults while appraising. This demonstrated the negative impact of ageing on crossing behaviour in terms of locomotion skills decline.

4 Model Description

We here briefly describe an agent-based model developed by the authors, and thoroughly discussed in [2, 7]. For reasons of space, we will omit the discussion of this baseline and we will only explain the general characteristics of the model, fundamental for the understanding of the proposed method for managing speed heterogeneity.

The model is an extension of the classic floor field model [5] and it employs the same space discretization by means of a rectangular grid of 0.4×0.4 m^2 cells. Positions of obstacles and the configuration of the environment is allowed by means of *spatial markers*, defining: (*i*) areas where pedestrians will be generated; (*ii*) obstacles; (*iii*) final destinations; (*iv*) intermediate destinations, used to divide the environment in smaller components and to allow the computation of higher-level paths for pedestrians to their final destination; (*v*) labels describing the name and typology of environment the cell belongs to (e.g. staircase, ramp, flat floor, etc.). This is aimed at modeling age-driven pedestrian dynamics while walking as characterized by heterogeneous behaviors in terms of speeds and other behavioral decisions that can be related to route choice (e.g. possibly avoiding stairs).

Space annotation allows the definition of additional grids to the one representing the environment, as containers of information for pedestrians and their movement. This describes the well-known *floor field* approach [5]. These discrete potentials are used to support pedestrians in the navigation of the environment, representing their interactions with static objects or with other pedestrians. Three kinds of floor fields are defined in our model:

- *path field* (static), which indicates distances from one destination;
- *obstacles field* (static), which indicates distances from neighbor obstacles or walls;
- *proxemic field* (dynamic), which provides information to identify crowded areas at a given time-step.

The walking behavior of simulated pedestrians is defined with probabilistic mechanisms. According to their *desired speed* and to the assumed duration of the time-step of the model, pedestrians are activated for the movement at each turn, and they can move in the Moore neighborhood of their position. The choice of movement is modeled in a probabilistic fashion by means of a utility function $U(c)$:

$$U(c) = \frac{\kappa_g G(c) + \kappa_{ob} Ob(c) + \kappa_s S(c) + \kappa_c C(c) + \kappa_d D(c) + \kappa_{ov} Ov(c)}{d} \tag{1}$$

$$P(c) = N \cdot e^{U(c)} \tag{2}$$

Parameters κ are the calibration weights allowing to configure a pedestrian-like behaviour and N of Eq. 2 is a normalization factor. Individual functions of Eq. 1 model respectively: (i) attraction towards the current target; (ii) obstacle repulsion; (iii) keeping distance from other pedestrians; (iv) cohesion with other group members; (v) direction inertia; (vi) moving in a cell occupied by another pedestrian (overlapping) to avoid gridlock in counter-flow situations.

4.1 Modeling Heterogeneous Speeds and Crossing Phases

In the literature related to the simulation of pedestrian dynamics, classic discrete models assume only one speed profile for all the population. Efforts towards the modeling of different speed profiles consider two main approaches: (i) *increasing agents movement capabilities* (i.e. they can move more than 1 cell per time step), according to their *desired speed*; in this way, given k the side of cells and n the maximum number of movements per step, it is possible to obtain n different speed profiles, less or equal to $n \cdot k$ m/step; (ii) modifying the current time scale, making it possible to cover the same distance in less time and achieving thus a higher maximum speed profile but at the same time allowing each pedestrian to *yield their turn in a stochastic way* according to an individual parameter, achieving thus a potentially lower speed profile.

The method supporting movements of more than a single cell can be effective, but it leads to complications and increased computational costs for the managing of micro-interactions and conflicts: in addition to already existing possible conflicts on the destination of two (or more) pedestrian movements, even potentially illegal crossing paths must be considered, effectively requiring the modeling of sub-turns. In addition, the expressiveness of this method is still limited: the maximum number of movements allowed per time step determines the number of speed profiles reproducible with simulations (e.g., with $v_{max} = 4$ cell per step and a turn duration of 1 second, simulations can be configured with 0.4, 0.8, 1.2 and 1.6 m/sec).

For these reasons, we decided to retain a maximum velocity of one cell per turn, allowing the model to reproduce lower speed profiles by introducing a stochastic yielding mechanism. Each agent has a parameter $Speed_d$ in its $State$,

Algorithm 1 Life-cycle update with heterogeneous speed

```
if $Random() \leq \alpha/\beta$ then
    if $updatePosition() ==$ true then
        $\alpha \leftarrow \alpha - 1$
    else
        $\beta \leftarrow \beta + 1$
    end if
end if
$\beta \leftarrow \beta - 1$
if $\beta == 0$ then
    $(\alpha, \beta) = Frac(\rho)$
end if
```

describing its desired speed. For the overall scenario, a parameter $Speed_m$ is introduced for indicating the maximum speed allowed during the simulation (described by the assumed time scale). In order to obtain the desired speed of each pedestrian during the simulation, the agent life-cycle is then *activated* according to the probability to move at a given step $\rho = \frac{Speed_d}{Speed_m}$.

By using this method, the speed profile of each pedestrian is modeled in a stochastic way and, given a sufficiently high number of step, their effective speed will be equal to the wanted one. But it must be noted that in several cases speed has to be rendered in a relatively small time and space window (think about speed decreasing on a relatively short section of *stairs*).

In order to overcome this issue, we decided to consider ρ as an indicator to be used to decide if an agent can move according to an *extraction without replacement* principle. For instance, given $Speed_d = 1.0m/s$ of an arbitrary agent and $Speed_m = 1.6m/s$, ρ is associated to the fraction 5/8, that can be interpreted as an **urn model** with 5 *move* and 3 *do not move* events. At each step, the agent extracts once event from its urn and, depending on the result, it moves or stands still. The extraction is initialized anew when all the events are extracted. The mechanism can be formalized as follows:

- Let $Frac(r) : \mathbb{R} \rightarrow \mathbb{N}^2$ be a function which returns the minimal pair $(i, j) : \frac{i}{j} = r$.
- Let *Random* be a pseudo-random number generator in $[0, 1]$.
- Given ρ the probability to activate the life-cycle of an arbitrary agent, according to its own desired speed and the maximum speed configured for the simulation scenario. Given (α, β) be the result of $Frac(\rho)$, the update procedure for each agent is described by the pseudo-code of Alg. 1. The method $updatePosition()$ describes the attempt of movement by the agent: in case of failure (because of a conflict), the urn is not updated.

This basic mechanism allows synchronization between the effective speed of an agent and its desired one every τ steps, which in the worst case (informally when $\frac{Speed_d}{Speed_m}$ cannot be reduced) is equal to $Speed_m \cdot 10^{\iota}$ step, where ι is associated to the maximum number of decimal positions considering $Speed_d$ and

$Speed_m$. For instance, if the desired speed is fixed at $1.3m/s$ and the maximum one at $2.0m/s$, the resulting $Frac(\rho) = \frac{13}{20}$, therefore the agent average velocity will match its desired speed every 20 steps.

In conclusion, the model is now suitable to reproduce the different crossing phases empirically observed and characterized. Pedestrians do not only have different individual desired walking speeds comparing adults and elderly, but also change their speed in accordance with crossing phases. The change of states is triggered by the possible perception of an oncoming vehicle, regarding its position and velocity.

5 Conclusions

The LONGEVICITY project is characterized by a methodological interplay between tools for social research, combined with approaches for the development of innovative technologies. The cities of the future will be characterized, in fact, by the growing presence of long-lived/active citizens, and it will then be necessary to design technologically advanced infrastructures and services to provide support to them.

The current paper described an ongoing activity based on the design of innovative agent-based model for the simulation of pedestrian crossing dynamics for the assessment of the level of walkability of urban areas. This is based on the possibility to model age-driven pedestrian dynamics as characterized by heterogeneous behaviors in terms of speeds and crossing behaviors. This work is aimed at providing applicative design solutions to enhance the level of comfort and safety of the elderly while walking through the city and to sustain their active ageing. In particular, this kind of research is potentially relevant to test the effectiveness of traffic management solutions (e.g., age-friendly traffic light systems) and to complement studies on outdoor ambient assisted environments in order to evaluate future transportation scenarios in Smart Cities.

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References

1. Bandini, S., Crociani, L., Vizzari, G.: Towards a more comprehensive estimation of social costs in pedestrian facilities. In: Proc. of the Workshop on The Challenge of Ageing Society: Technological Roles and Opportunities for Artificial Intelligence in conjunction with the 13th Conference of the Italian Association for Artificial Intelligence,(AI* IA 2013), Turin, Italy (2013)

2. Bandini, S., Crociani, L., Vizzari, G.: An approach for managing heterogeneous speed profiles in cellular automata pedestrian models. J. Cellular Automata **12**(5), 401–421 (2017)
3. Bandini, S., Gorrini, A., Nishinari, K.: Crossing disciplinary borders through studying walkability. In: International Conference on Cross-Cultural Design. pp. 491–503. Springer (2016)
4. Berzi, C., Gorrini, A., Vizzari, G.: Mining the social media data for a bottom-up evaluation of walkability. arXiv preprint arXiv:1712.04309 (2017)
5. Burstedde, C., Klauck, K., Schadschneider, A., Zittartz, J.: Simulation of pedestrian dynamics using a two-dimensional cellular automaton. Physica A: Statistical Mechanics and its Applications **295**(3-4), 507–525 (2001)
6. Crociani, L., Piazzoni, A., Vizzari, G., Bandini, S.: When reactive agents are not enough: Tactical level decisions in pedestrian simulation. Intelligenza Artificiale **9**(2), 163–177 (2015)
7. Crociani, L., Zeng, Y., Vizzari, G., Bandini, S.: Shape matters: Modelling, calibrating & validating pedestrian movement considering groups. Simulation Modelling Practice and Theory (2018)
8. Duncan, D.T.: Whats your walk score®?: Web-based neighborhood walkability assessment for health promotion and disease prevention. American journal of preventive medicine **45**(2), 244–245 (2013)
9. Dzhambov, A., Dimitrova, D., Aleksandrova, M.: Adapting a gis version of the irvine-minnesota inventory (imi) for bulgarian settings. Scripta Scientifica Salutis Publicae **2**(1), 12–22 (2016)
10. Feliciani, C., Crociani, L., Gorrini, A., Vizzari, G., Bandini, S., Nishinari, K.: A simulation model for non-signalized pedestrian crosswalks based on evidence from on field observation. Intelligenza Artificiale **11**(2), 117–138 (2017)
11. Gorrini, A., Bertini, V.: Walkability assessment and tourism cities: the case of venice. International Journal of Tourism Cities (2018)
12. Gorrini, A., Crociani, L., Vizzari, G., Bandini, S.: Observation results on pedestrian-vehicle interactions at non-signalized intersections towards simulation. Transportation Research Part F: Traffic Psychology and Behaviour **59**, 269 – 285 (2018). https://doi.org/https://doi.org/10.1016/j.trf.2018.09.016
13. Gorrini, A., Vizzari, G., Bandini, S.: Age and group-driven pedestrian behaviour: from observations to simulations. Collective Dynamics **1**, 1–16 (2016)
14. OECD: Ageing and transport: Mobility needs and safety issues. Organization for Economic Co-operation and Development (2001)
15. Organization, W.H.: Global age-friendly cities: A guide. World Health Organization (2007)
16. Speck, J.: Walkable city: how downtown can save America, one step at a time. macmillan (2013)
17. United Nations: World population ageing 2013. New York, United Nations, Department of Economic and Social Affairs, Population Division (2013)
18. Yin, L.: Street level urban design qualities for walkability: Combining 2d and 3d gis measures. Computers, Environment and Urban Systems **64**, 288–296 (2017)