PEDESTRIAN NETWORK DESIGN AND OPTIMISATION BASED ON PEDESTRIAN SHORTCUTS AND NEEDS

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Abstract

We have designed a new approach to build an optimal pedestrian network. Modelling and building optimal walkway network is a big challenge. It is a complex task, which generally get more complicated with increased functionality and size of a city. In this study is walkway network considered as optimal, when no shortcuts are used by pedestrians to reach their target location. Pedestrian shortcuts are also understood as a tool for walkway network optimisation. Optimisation of walkway network also includes simplification and shaping. There have been investigated shortcuts in cities Olomouc and Ostrava. Focus has been taken on the surrounding environment of shortcuts and proportion of the initial and shortened distance. We found that there are regularly taken shortcuts by pedestrian when at least 18% of the original walkway distance is shortened. Also we found that there are two exceptions. Firstly, at the edges of the rectangular parts and at the right angles of the network are made short paths. Secondly, at time depending through-flows, such as zebra crossing, public transport, bus or railway stations, are the shortened distanced even smaller. In this case is important to consider the direct visibility of the target location (station, traffic lights etc.). The first problem can be solved with changing the shape of paths. In the second case is needed an optimisation process. Furthermore in this study was considered the proportion and density of the walkway network in the city and surface of the network and its aesthetic perception.

Keywords: pedestrian network, optimisation, shortcut, distance, human perception, walkability

INTRODUCTION

Since ages, the people move from one place to another. Walking is the most natural and oldest human type of movement. The purpose, ways and speed of motion have changed over the past centuries, but walking still stays most common. This is based on the observation that most people travel only short distances, while a few regularly move over hundreds of kilometres (Gonzalez et al., 2008). Even if a person is taking a different way of transportation, it has to walk to the starting point of that particular locomotion. For example the passenger has to walk to the parking lot before taking distance using a car. Pedestrian trajectories are often approximated with various random walk or diffusion models (Brockmann et al., 2006; Havlin and Ben-Avraham, 2002). But none of them fully satisfies the reality. The behaviour of human motion in space is close to the properties of Lévy motion (flight). But in contrast with the random trajectories predicted by the prevailing Lévy flight and simulated random walk models, human trajectories are showing a high degree of spatial and temporal regularity. Each individual is being characterized by a time independent characteristic travel distance and a significant probability to return to a few highly frequented locations (Gonzalez et al., 2008). In the real world few long distances are often made in a single step. But they are mostly done by other ways of transport. Thus we focus on small distances and walkability in cities, what is important for development and design of pedestrian networks. Pedestrian can choose the route to move according to its perception of the environment and its goals (Vizzari, G, and Manenti, L., 2012). The movement patterns generated by purposive and by random walkers are the same (Jiang and Jia, 2011). Walker is moving fully autonomous with its personal needs and attributes in mind. Walkability of a particular area is a property of environment-human system. It can be properly modelled only when interweaving environmental and human properties (Jonietz, D, and Timpf, S., 2012). The literature on urban design and walking has often emphasized more macro-scale features of environment system, such as block length and number of intersections, which are easier to measure using remote sensing and GIS (Cervero and Kockelman, 1997; Greenwald and Boarnet, 2002; Krizek, 2003; Alfonzo, 2008). Urban designers, in contrast, emphasize the importance of micro-scale features (Carr et al., 1992; Gehl and Gemzøe, 2004). Such micro-scale features are including the presence of street trees, pathway width, the presence of abandoned buildings etc. (Alfonso, 2005). It is necessary to involve both types of features. Concerning human environmental perception in general, when people are looking at objects, they perceive their action-related properties, rather than their physical attributes (Gibson, 2004). These properties, also termed affordances, are determining whether the person is walking or not (Alfonzo, 2005). Hierarchically ordered walking needs are feasibility (lowest resp. basic need), accessibility, safety, comfort and pleasurability (highest one). First the basic needs have to be fulfilled, before higher level needs are even considered. For example, if a walkway in park provides pleasurable and comfortable walking or running but lack of safety, it will not be considered as usable by pedestrians. In order to have effective walkway network it is essential to build the network with regard to aforementioned concept of hierarchical needs.

PEDESTRIAN NETWORK

Optimal pedestrian network planning and design is challenging problem, which is keeping attention of urban planners, architects, geographers, psychologists and others. The understanding of basic laws governing human motion remains limited owing to the lack of tools to monitor the time-resolved location of individuals (Gonzalez et al., 2008). A proper investigation and monitoring of movement would also violate against human rights. Many aspects of walking are difficult to experiment within the real world and can be reliably explored through computer models (Torrens et al., 2011). High-fidelity representation of human walking behaviour is required and model-builders often use agent-based models as a mechanism for representing individual agency in simulation, but in many cases they specify the models with coarse, abstract representations of movement (Hughes 2003). Crowds of pedestrians represent a complex system: the overall behaviour of the system can only be defined in terms of the actions of the individuals that compose it, and the decisions of the individuals are influenced by the previous actions of other pedestrians sharing the same space. Despite the substantial amount of studies and effort of researcher, we are far from complete understanding this complex system (Vizzari and Manenti, 2012). Because of the lack of knowledge, inability to truly reconstruct the behaviour of pedestrian motion, difficulty with deriving rules for agent walking behaviour, reliability of associated movement paths with the human reasons and complexity of the system, we decided to base our pedestrian network on different approach (Fig 1.), but relying on aforementioned facts and results. The human perspective has been neglected in both public space design and management. Places are proposed, built and assessed with goals of space managers, space designers and its clients instead of address people's needs (Carrs, 1992). In this article, we introduce a scheme to resolve this problem by adopting the pedestrian network to pedestrian needs rather than vice versa. Pedestrian environment has to be adapted to pedestrians too. More or less pedestrian friendly environment will rise or decrease the walkability of city and thus control pedestrian flows if needed. In the first place it has to build a basic framework connecting all nodes of network (bus stations, schools, housing units, parking lots etc.) using minimal number and length of walkways. Material used to build this basic frame of network has to be easily removable and less expensive because of the high probable change or removal. This first step will make all nodes accessible, but the network will not be optimal yet. Optimisation will be done in a cycle, in which the pedestrians will choose their own pathway. Their pathways will turn into pedestrian walkways according to frequency of usage and distances they cut and shorten. The optimisation is done until no new pathways (shortcuts) are generated and meanwhile all of them are regularly used by pedestrians. After every cycle, the environment of network has to be reconditioned. So there will be no shortcuts between the nodes and edges of the pedestrian network (e.g. grassing or any other land cover change to reset conditions). The influence of pedestrians using older variant of the network has to be eliminated, so the old shortcuts have to vanish. This is an important step, because new shortcuts should appear according to the upgraded network and human's experiences using it. This is based on the fact, that a person moving through a transportation network (by any kind of transport) perceives its walkability as an affordance that comprises different qualities and satisfactions. So he can later on choose an alternative way of movement. This change of environment by tracking out a shortcut can result into change in pedestrian network. Other changes of environment such as building a new building, communication, zebra crossing etc. are leading also to changes in pedestrian network. On the other side a particular walkway can be changed back to another type of land cover, if not used by pedestrians anymore. Pedestrian network is a dynamic system, which develops continuously with its environment and users. Fig. 1 depicts the optimisation process, where the changes of human-environment system (box change in environment) determine the change of pedestrian network (box change in pedestrian network) or its surroundings (box reset of environment) or both of them.

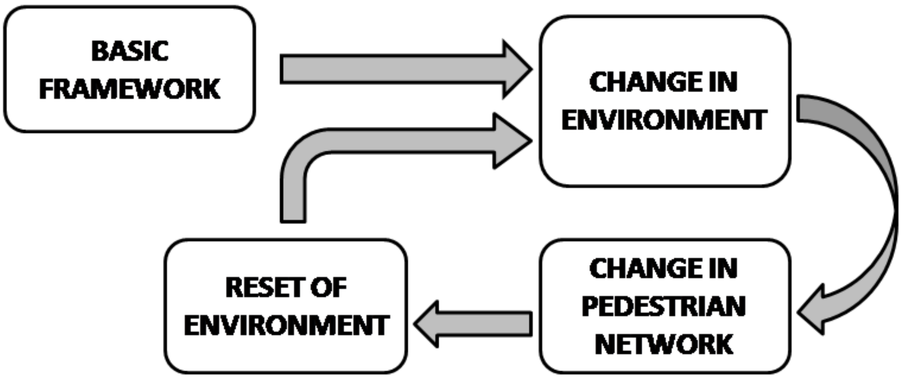


Fig.1. Outline of pedestrian network optimisation.

SHORTCUT BASED OPTIMISATION

The aforementioned pedestrian network development is based on theory of ant colony optimisation. However the human perception of a world and expectations in life are more sophisticated. Theorems used in this article are changed according to the purpose of walkway network. The goal is to achieve a pedestrian network with properties, which would satisfy almost all pedestrians. The social interaction between ants (or insects, animals) is often established through indirect stimulation, which is also called stigmergy (Grasse 1959). Ants deposit pheromones on the ground in order to mark paths, which should be followed by the other members of same colony (Dorigo et al., 2006). The trace left in the environment can be understood as a form of communication between agents. On the other side pedestrians are more intelligent agents and have a good memory. A particular shortcut in the pedestrian network can be understood as a trace left in the environment by other agents. When pedestrian is approaching shortcut (or crossroad), he perceives the environment and its walkability. Finally pedestrian makes decision and continues in walking. Passing through an unknown area pedestrian evaluates the chosen and optional opportunities for passing towards its target location. Pedestrian finds the optimal solution comparing previous experience or observation of the alternatives with the chosen way in the area. Thus the risk of taking twice or more times wrong route is significantly decreased. Another big challenge is the purpose of walking. The purpose of walking determines the selected route (e.g. to crown a dog, shopping, work etc.). Also the environment of walkway takes an important place. Many people take a pleasure passing through or next to a notable or comfortable place (touristic attraction, park, fountain, crowded localities, etc.). So they can walk longer distance, even when they are aware of doing it. Comparing to swarm intelligence (shortest distance) is the problem of building optimal pedestrian network more complicated and complex (hierarchical needs, different purpose). Deficiencies of pedestrian networks are leading pedestrians to walk outside the network. So shortcuts are representations of human needs to reach their goals.

CASE STUDIES AND RESULTS

In our study we analysed 163 shortcuts in cities Olomouc and Ostrava. We tried to deduce generalities from the analyses of gathered attributes and so provide useful guidelines to planers and researchers. As expected; the shortcuts are mostly located in more populated residential areas. Shortcuts occurred most frequently in residential district Nové Sady in Olomouc. Shortcuts are abundant in public space, alongside communications, when pedestrian network ignores natural and artificial barriers (Fig. 2). Next ones are connected with poor planning or optimisation of pedestrian network, such as missing edges, unconnected nodes of pedestrian network, small capacity, wrong placement of zebra crossing etc. (Fig. 3). Short pathways are also tracked out at the edges of the rectangular parts and at the right angles of the network. It can be eliminated with appropriate shaping. These localities are the most crucial for pedestrian network optimisation.

Fig. 2. Left: Shortcut as a result of outlet between barriers made of two blocks of flats. Middle: Green urban space with shortcuts in residential district Nové Sady. Right: Shortcut along the railway just next to Railway station in Olomouc (Source Pachta).

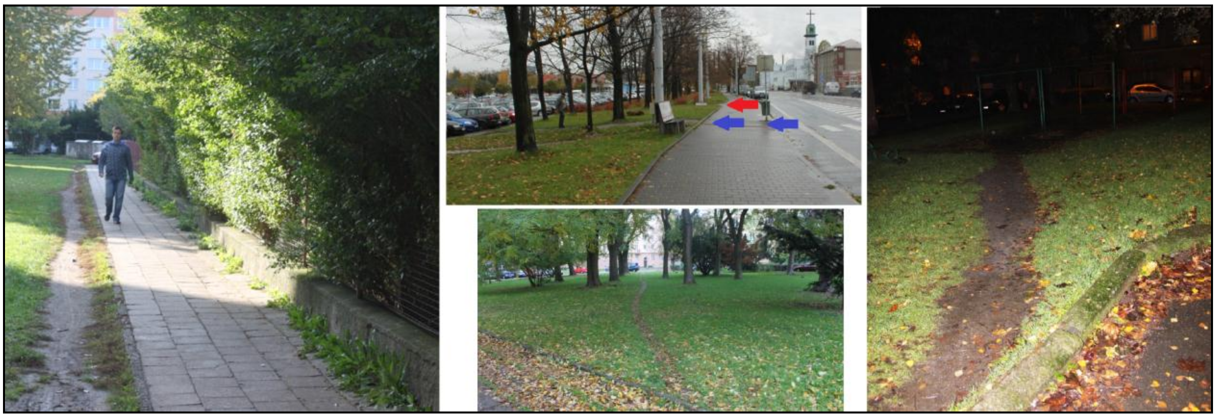


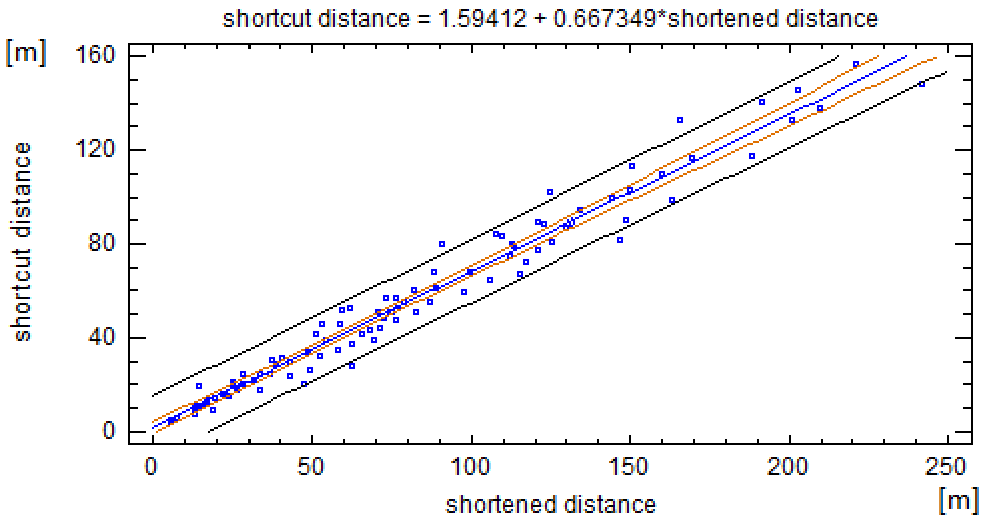
Fig. 3. Left: Maximal pedestrian flow overreaches the capacity of the cobblestone pavement. It caused shortcut in residential district Nové Sady. Middle up: Wrong placement of zebra crossing leaded to two shortcuts and unused cobblestone pavement in Moravská Ostrava. Middle down: Missing sidewalk around the park force pedestrian walk through the street or shortcut in Poruba part of Ostrava. Right: Playground is not connected with the pedestrian network, thus four shortcuts have been tracked out. (Source: Mudron)

All analysed shortcuts are located in urban areas. Average length of analysed shortcuts is 42.8 meters, median 31.4 meters. Shorter shortcuts occurred more often than longer ones. Most frequently in the interval of 15-20 meters in length. The width varied from 15 cm to 120 cm. The measurement was made with 50m long measuring tape. The lengths were measured along the centre line of walkways. We analysed two dependencies. The measured lengths were rounded off to one decimal place. First, it was investigated the dependence of shortcut distance on proportion of the initial and shortened distance. The proportion shows the percentage of saved distance by taking particular shortcut. We investigated if length of a shortcut has an influence on optimisation (using simple regression), viz. longer shortcuts save more percentage of initial length and shorter ones less percents or vice versa. In the analyses we were not able to find any dependence. We have also used various types of models. The best R-squared value has Reciprocal-X model (Table 1), but it represents poor estimate (17 percent of variation of the data explained by the fitted line). So we can state, that long shortcuts as well as short ones have statistically the same optimisation effect according to distances.

Table1. Comparison of R-squared values of alternative models used to explain the empirical data.

Model	Correlation	R-Squared	Model	Correlation	R-Squared
Reciprocal-X	-0.0416	17%	Exponential	<no fit>	-
Logaritmic-X	0.0381	15%	Double square root	<no fit>	-
Squared-X	0.0350	12%	Multiplicative	<no fit>	-
Square root-X	0.0343	12%	Reciprocal-Y sq. root-X	<no fit>	-
Linear	0.0322	10%	Logarithmic-Y sq. root-X	<no fit>	-
Reciprocal-Y	<no fit>	-	Squared-Y sq. root-X	<no fit>	-
Logaritmic-Y	<no fit>	-	Sq. root-Y logarithmic-X	<no fit>	-
Squared-Y	<no fit>	-	Reciprocal-Y logarithmic-X	<no fit>	-
Square root-Y	<no fit>	-	Squared-Y logarithmic-X	<no fit>	-

Second analyses investigated the dependence of shortcut length on initial shortened distance. We wanted to found the relation between the aforementioned distances. Linear model will underline the previous analyses. As expected, there is a strong linear dependence of shortcut length on initial shortened distance (Fig. 4.). The linear model fitted almost perfectly (Fig. 4, R^2 96%). We found that the variance of shortcut distance values is increased with increase in shortened distance. According to this model if a pedestrian is taking shortcuts in total length of 200 meters on the way home, he is saving 96 meters or 1 minute and 9 seconds (speed 5 km/h, circa 1.4 m/s).



Comparison of Alternative Models

Model	*Correlation*	*R-Squared*
Multiplicative	0.9841	96.84%
Double square root	0.9827	96.57%
Double reciprocal	0.9825	96.53%
Linear	0.9803	96.10%
Double squared	0.9731	94.70%
Square root-X	0.9625	92.63%
Logarithmic-Y square root-X	0.9599	92.14%

Fig.4. The output shows the results of fitting a linear model to describe the relationship between shortcut distance and shortened distance. Table shows the results of fitting several curvilinear models to the data. Of the models fitted, the double square root model yields the highest R-Squared value with 96.8% because of the higher variance of larger values.

We found that there are regularly taken shortcuts by pedestrian when at least 18% of the original walkway distance is shortened. The average saved distance (when walking through a shortcut between two locations connected to pedestrian network instead of taking the pedestrian network) is 29.7% of the distance taken through the pedestrian network. Corresponding to topology and environment we evaluated the density, neighbourhood and connections of shortcuts. Most of the shortcuts are in high populated areas and in poorly connected nodes. Focus has been taken on the surrounding environment of shortcuts, but we were not able to gather enough data according to complexity of the problem. Poorly connected (up to three walkways) nodes, which are daily visited by a large number of pedestrians (hospital, school, administrative departments, psychological office, etc.), are associated with higher number of shortcuts. At time depending through-flows, such as zebra crossing, public transport, bus or railway stations, are the saved distances smaller than the average aforementioned value. The direct visibility of the target location is influential in this case. Most of the shortcuts are connecting the edges and creating triangles in the pedestrian network. They represent shorter ways of node connections. But shortcuts (6% in our study area), which are creating quadrilateral, pentagonal or polygons with more sides are revealing missing edges (or curves) of the network. In the study area are common pentagons, hexagons and also one heptagon in Nový Svet district of Olomouc. It is necessary to gather more information to make reliable conclusions about other functional structures. For example in the case of commercial or shopping zones shortcuts are following different rules. It seems to be interconnected entrances with each other (whatever with pavement or shortcut). This phenomena should be deeper studied. The last but not least was studied the aesthetic component of the problem. Shortcuts do not fit into the cities. There is a notable group of people, who does not agree with usage of shortcuts. They see it like violation against public order. Shaping and design of new paths in the cities is very important. Surfaces as bulk gravel for open space or cobblestones for sidewalks of communications and historical city centres fit better into the environment. Colour and shape is important too. Bulk gravel is the easiest removable and nature-friendly material. It fits in the fringes of cities and parks more than traditional surfaces (asphalt, concrete, etc.). It is also good to use this material in downtown green areas, where is high proportion of artificial material all around. In planning, design and building new parts of pedestrian network should not be skipped any aforementioned aspect, because pedestrians perceive the environment as a whole system. Only when this system will be build according to pedestrian needs, they start to fully use it. Only then the network starts to fulfil more purposes than just a simple medium of movement (relaxation, social interaction, pleasure, etc.).

CONCLUSIONS AND DISCUSSION

In this paper, the outlines of a new concept for modelling and design of pedestrian network is presented. The concept is based on shortcuts made by pedestrians according to their needs. Following the results, the pedestrians have evidently found a faster way of movement through the urban environment in our study area. As reported in results these shortcuts are found in specific locations, which are prone to tracking out new shortcuts. This is notable in other cities too (using aerial images, maps.google.com, terrain research in Magymaros and Budapest). It seems that the reasons taking the shortcuts are the same. People are living in hectic time, where every second counts. Some others are indolent to walk longer distances. This makes a call for fast and walkable environment, especially in the cities. Recent urban areas, especially in the industrial areas (such as Ostrava), are facing various problems such as air pollution. Due to high level of motorized transportation is this problem worsened. Modern strategy of sustainable transportation planning set a goal to increase the relative share of non-motorized transport such as cycling or walking. A precondition for this is to improve the pedestrian network in existing cities and plan optimal networks in the new parts of cities, town districts or cities (Saelens et al., 2003). One of the solutions is to improve the walkability of city, the level at which is the city suitable for walking. Shortcuts are indicating the problems. It is important first to understand the reason why places are ignored or used by pedestrians. Building the network according to pedestrians can be later on studied and it can show reasonable answers for building and modelling pedestrian networks by traditional methods. It should be gathered more information and also use different resources. It would be useful to interview anonymously the pedestrians, who are using shortcuts. Count the number of pedestrians. It should be done twice: before and after change in environment or pedestrian network. Some weather conditions, e.g. fresh snow, can reveal the patterns of pedestrian movements. Optimal pedestrian network also decreases the number of traffic accidents. It increases the number of pedestrians. Physical activity of walkers is a key to maintaining their health.

REFERENCIES

Alfonso, M. A. (2005) To Walk or not to walk? The hierarchy of walking needs. In Environment and Behaviour, 37(6), 808-836.

Alfonzo, M., Boarnet, M., Day, K., McMillan, T., Anderson, C. (2008) The relationship of neighbourhood built environment features and walking. Journal of Urban Design, 13(1), 29–52.

Brockmann, D. D.,Hufnagel, L., Geisel, T. (2006) The scaling laws of human travel. Nature, 439, 462-465.

Carr, S., Francis, M., Rivlin, L. G., and Stone, A. M. (1992): Public space. Cambridge, MA: Cambridge University Press.

Cervero, R., Kockelman, K. M. (1997) Travel demand and the 3Ds: Density, diversity, and design. Transportation Research Part D, 2, 199-219.

Dorigo, M., Birattari, M., Schutze, T. (2006) Ant colony optimisation. Artificial ants as a computational intelligence technique. IEEE Computational Intelligence Magazine, 28-39.

Gehl, J., Gemzøe, L. (2004) Public spaces, public life. Copenhangen, Danish Architectural Press.

Gibson, J. J. (1977): The theory of affordances. Perceiving, acting,and knowing: Toward an ecological psychology, Mahwah, NJ: Lawrence Erlbaum, pp. 67-82.

Gonzalez, M., Hidalgo, C. A., Barabási A.-L. (2008) Understanding individual human mobility patterns in Nature, 453, 779–782.

Grassé, P. P. (1959) La reconstruction du nid et les coordinations interindividuelles chez bellicositermes natalensis et cubitermes sp. La theorie de la stigmergie: essai d'interpretation du comportament des termites constructeurs. Insects Sociaux, 6, 41-80.

Greenwald, M., Bournet, M. (2002) The built environment as a determinant of walking behaviour: Analyzing non-work pedestrian travel in Portland, Oregon. In Transportation Research Record, 1780, 33-42.

Havlin, S., Ben-Avraham, D. (2002) Diffusion in disordered media. Advances in Physics, 51(1), 187-292.

Hughes, R. L. (2003) The flow of human crowds. In Annual Review of Fluid Mechanics, 35, 169–82.

Jiang, B., Jia, T., (2011) Agent-based simulation of human movement shaped by the underlying street structure. International Journal of Geographical Information Science, 25(1), 51-64.

Jonietz, D, Timpf, S., (2012) Towards an affordance-based model of walkability. In Proceedings of the 15th International Symposium on Spatial Data Handling, 22-24th August, 2012, Bonn.

Krizek, K. (2003) Residential relocation and changes in urban travel: Does neighborhood-scale urban form matter? In Journal of the American Planning Association, 69, 265-281.

Saelens, B. E., Sallis, J. F., Frank, L. D (2003) Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures. In Annals of behavioral medicine, 25 (2), 80-91.

Torrens, P., Xun, L., Griffin, W. A. (2011) Building agent-based walking models by machine-learning on diverse databases of space-time trajectory samples. In Transaction in GIS, 15, 67-94.

Vizzari, G, Manenti, L., (2012) An agent-based model for pedestrian and group dynamics: Experimental and real-world scenarios. In Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems, Vol. 3, pp. 1341-1342, 4-8th June, 2012, Valencia.