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Pedestrian Simulation for the Sustainability of the Built Environment



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If sustainability means to meet the needs of the present without compromising the ability of future generations, pedestrian simulation software can contribute to this aim in the field of building design and engineering. Simulation of human walking allows to identify planned or existing flaws regarding pedestrian comfort and security in buildings, urban areas or transport facilities that will threaten the current and future use of these facilities. Significant follow-up costs due to refurbishments, extensions or corrections of the built environment can be avoided by using pedestrian simulation technology.

There are many reasons why pedestrian or human movement simulation can make sense in architecture, landscaping, urban planning and other fields. The most significant one is certainly the fact that now more than 50 percent of the world's population are living in cities or suburban areas. In the future, more people than ever before will have to move safely and efficiently in more and more dense urban areas. This puts a strain on urban transport infrastructure (car traffic, public transport, metros, trams, buses etc.) as well as on urban infrastructures (buildings, areas, places etc.) (FIG. 1).



Figure 1

Introducing “the pedestrian”

Until recently, pedestrian issues have not been at the forefront of research and practice in architecture, transport, urban planning and security studies. In architecture, buildings are planned with functionality, space and architectural beauty in mind. Although all of these buildings are after construction primarily used by walking, seated or otherwise involved humans, it was not a serious consideration until recently how they might move and feel comfortable within a given building or area.

In the transport domain, traffic studies treated passengers mainly as “objects” moved by trains, cars, metros or trams. They rarely considered pedestrian flows moving people efficiently and safely – or unfortunately not that efficiently and safely - from A to B.

This widespread lack of interest in pedestrian issues was based on one side on cultural perspectives and politics that stressed building new highways and new highspeed railways and leaving aside the needs of pedestrians, and on the other side on the lack of a suitable technology to analyze pedestrian problems. With sustainability, CO2 reduction and global warming issues raising on the agenda, environmental friendly transport and pedestrian zones were coming into focus. In addition, new simulation technologies and increased computer performance allowed to analyse pedestrian movement more realistically.

Pedestrian simulation technologies

Since the 1950s there were attempts to simulate pedestrian flows with varying mathematical models, mostly based on flow models that modelled pedestrians as liquids flowing with certain characteristics through buildings and areas. Obviously, these technologies were not able to model pedestrians individually and therefore lacked realistic representation.

In the 1990s, the advent of object oriented programming and specifically agent-based simulation, allowed for the first time to model pedestrian movement accurately, although the development of respective algorithms is still an ongoing process due the complexity of pedestrian movement in itself.

Especially the gathering of empirical pedestrian data for algorithm improvement and validation purposes is a main bottleneck in the further development of the technology. Data gathering studies based on video capturing and manual or semi-automated pedestrian trajectory extraction are expensive and only rarely conducted. Validation of simulation models based on these empirical data is therefore a main issue in the further spread and use of the technology.

Still, for the first time it's now possible to model pedestrian movement with high precision and accurateness in different settings. Individual pedestrian characteristics and properties like speed, breadth, aggressiveness and many others can now be taken into account for the simulation of pedestrian flows. State-of-the art pedestrian microsimulation software shows, without explicitly programming it into the model, pedestrian macrobehaviors like lane formation in passages and other behaviors that occur in reality by self-organization.

Pedestrian simulations can now be adapted to model people from different countries with different cultural backgrounds, ages, genders and preferences. As empirical studies show, all these factors can be reflected in the walking behavior of pedestrians. Latest studies are including behavioral psychology like visual preferences, communication and other "soft factors" into pedestrian simulation models. The main issue in all these research activities is the question to what extent all these factors that can be followed down to the slightest detail really matter in practical applications (FIG. 2).

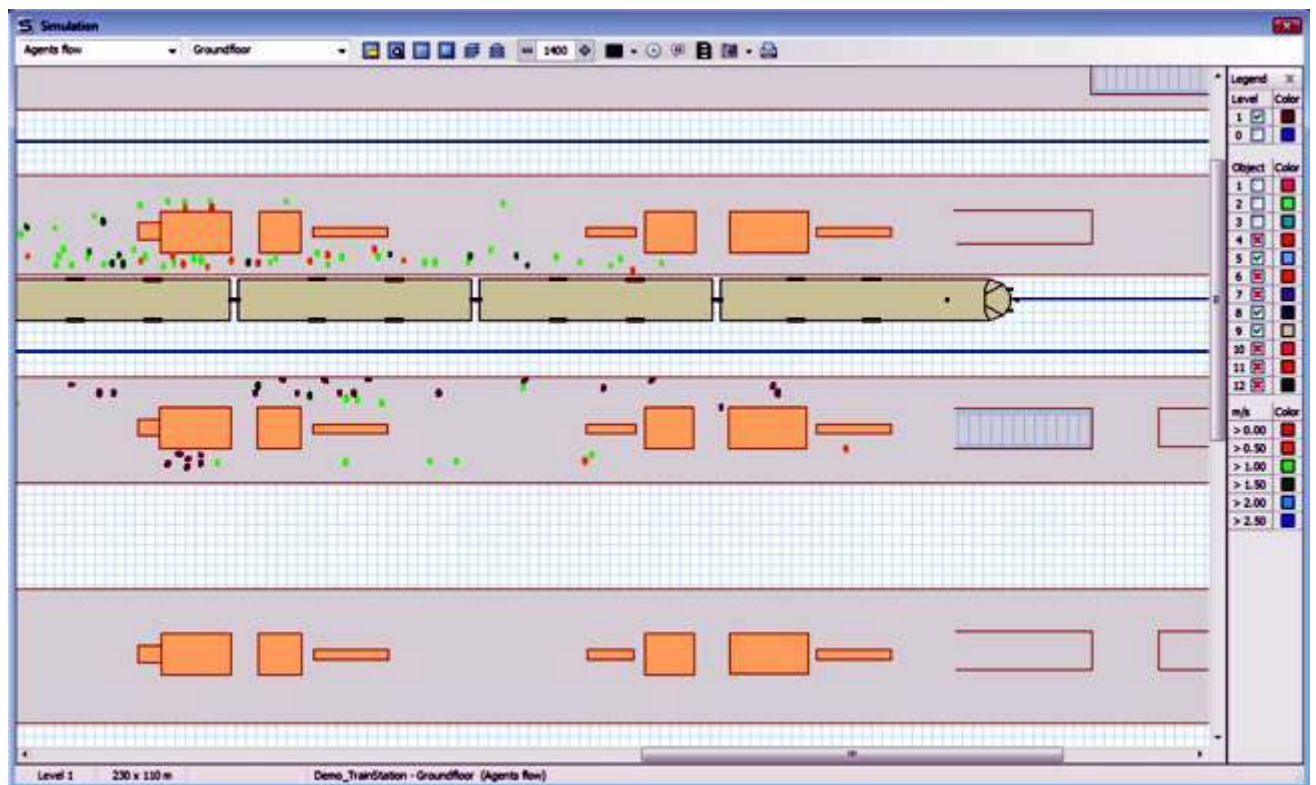


Figure 2

General applications

Humans are virtually moving and walking everywhere on this planet. Therefore it's no wonder that, in principle, pedestrian simulation can be applied in a broad range of fields. Yet more specifically at this time, most of the real-world applications are represented either by a high occurrence of pedestrians in some spatial area (e.g. in transit stations, airports, events etc.), or by security applications as for example evacuations of large buildings, shopping centers, in case of natural disasters or sports stadia etc.

Basically, pedestrian simulation technology allows to model human movement in all settings where a spatial design or plan is available that defines the walking paths of the pedestrians.

The realistic modeling and simulation of pedestrians in all these applications allows to analyze a broad range of issues, for example potentially dangerous densities of people, bottlenecks, transfer times, evacuation times, suitable layout configurations and other measures of effectiveness. Based on these evaluations, spatial design and facility improvements or changed guiding principles are usually recommended to improve crowd flows. As experience shows, small changes can often have a large impact on crowd flows if suitably set.

Complex phenomena like crowd flows often generate counterintuitive behavior and results that complicate engineering of pedestrian facilities by analytical methods alone. Simulation can help to deal efficiently and prospectively with these complex behaviors and outcomes.



Figure 3

Real-world applications

To get more concrete, SimWalk for example, a pedestrian microsimulation software developed by Savannah Simulations AG, is used worldwide by transport engineers, architects, traffic planners, security engineers and researchers for pedestrian analysis. Pedestrian studies are either conducted during the planning phase of buildings or facilities, or during operation to evaluate efficiency or security improvements.

A transport application example is the passenger study of Brisbane Central Station, Australia, conducted with SimWalk. This study evaluates peak hours of passenger demand at Brisbane Central station, analysing future station capacity threats as well as security and evacuation scenarios. Is the existing station infrastructure capable to process future passenger demand? How long does it take to evacuate passengers in case of emergency?

Are existing connection and transportation devices (escalators, stairs, elevators etc.) sufficient for dealing with actual and future passenger demand? Where do occur pedestrian bottlenecks or high densities that are potentially dangerous for passengers?

To answer these questions can have a significant impact on future station layout and operations. Similar questions are raised in many transportation passenger studies, for example in another simulation conducted at Wien Westbahnhof, Austria.

Another example from the field of event / urban planning is a crowd flow analysis of the Haji event, Mekka, Saudi Arabia, that includes millions of pilgrims conducting a ritual march every year round the holy Ka'aba (FIG.3). A high number of pilgrims marching in a narrow area causes recurring injuries and disasters every year.

Therefore it is a vital question how to improve crowd flows in this area. Among a range of different studies by other consultants and researchers to come up with solutions for these major problems, a study using SimWalk was conducted. A simulation result was to implement improved spatial guiding principles in addition to changed timing schedule to decrease high densities of pilgrims, potentially leading to panic and disaster. Although panic is often mentioned to have a major impact on crowd flows, it is not yet clear based on empirical studies that panic is in fact a recurring and determinable behavior of people in danger.

Another important field of application of human movement studies are evacuation simulations in case of fire in buildings or other emergencies that require fast and secure egress of people. One example, conducted with SimWalk, is the evacuation simulation of a football stadium in Philadelphia, USA.

The software was used to create an evacuation model of 15'000 to 18'000 people during the graduation event at Franklin Field Stadium. There were conducted multiple controlled and non-controlled simulations.

The simulation results changed from 15 to 16 minutes in general. In 2007, the University of Pennsylvania's Division of Public Safety managed an actual evacuation event in the Franklin Field Stadium. The evacuation experiment was timed and the model was right on.



Figure 4

Working with pedestrian simulation

Are there any specialities in using software for pedestrian simulation? In general, all pedestrian simulations are based on the spatial design of existing plans – mostly CAD format, some times GIS data for wider areas – that are imported into simulations as the background environment for pedestrian flows. In addition, pedestrian flow directions are generated by assigning origin-destination matrices for pedestrian groups as well as individual properties like walking speeds, body diameters etc.

As mentioned above, empirical input data as person countings/estimations or distribution of pedestrians types in this area (business people, elderly) are of crucial importance to have a realistic simulation output. There are many companies and software that are specialized on people counting and trajectory extraction that can be used to gather input data. As for simulation in general, after having determined the model and the input data, different simulation experiments are conducted based on specifications and research goals.

3D visualization

Increasingly, 3D visualization of human movement is becoming mandatory in pedestrian simulations, although 3D visualization adds additional complexity to the already complex modeling of pedestrian movement in 2D.

Visualization of human walking is already a complex process in 2D where pedestrians are modelled as points or other shapes. The complexity of walking in 3D is even more complex, adding modeling and simulation of body parts, leg and arm movements as well as head and whole body characteristics.

Additionally, there is a trade-off between level of detail and simulation performance. A fine grained, game-like 3D visualization of thousands of pedestrians requires enormous processing power and is normally not feasible for commercial simulation projects. Still, the increasing processing power of computer hardware and better algorithms will improve this situation and lead to more common usage of 3D visualization in pedestrian simulation software as in CAD and GIS software (FIG. 4).

As a closing remark, pedestrian simulation adds in our view an important additional analysis perspective for assuring the sustainability of the built environment and of spatial design in general - a perspective taken by the day-to-day human users. Helping people to move comfortably and safely in all these environments will help to prevent costly mistakes and add to the value of every project.

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