Airport Schiphol

Behavioral Simulation of a Design Concept

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Abstract: *In this paper, we introduce an agent-based simulation of passengers in airport terminal buildings. A case study is described during which a prototype simulation tool is used to test the impact of a conceptual design change in an existing airport terminal building. We illustrate how this real-time, geometry-aware simulation can be generalized and integrated into the design process to support designers in configuring the spatial layout of public and functional buildings.*

Keywords: *User behavior; agent-based simulation; airport terminal; design process; design evaluation.*

Introduction and existing work

Currently, the simulation of building performance factors is mostly focused on physical aspects such as temperature, lighting and air-conditioning. The simulation of human behavior in the built environment, however, is limited to only a few applications: On the building-level a constant stream of research is being done in the field of user behavior simulation. However, research on pedestrian behavior and its simulation has been undertaken either at an urban scale or for evacuation situations (Helbing et al 2001, Zheng et al 2009). The simulation of human behavior in everyday situations as a means to evaluate performance criteria of buildings (Tabak et al 2008) is still under-represented. To date, only a limited number of readily available models and tools exist to help designers predict the behavior of users in airport terminals (Joustra and Van Dijk 2001, Verbraeck and Valentin 2002, Takakuwa and Oyama 2003).

The airport terminal

The case study, covered in this paper, consists of validating a conceptual design change regarding Departures Terminal 2 of Amsterdam Schiphol Airport. The terminal building suffers a number of conspicuous problems, mostly concerning the way-finding of passengers. While these might be exemplary for airport terminals in general, in this research project we look specifically at this particular terminal.

While there is a trend in checking in from the internet, which has reduced some of the load on the terminal, this has not removed the cluttering of passengers in front of displays with flight information. Since these displays are hung right above the regular traffic space, this obstructs the other travelers. Other problems include that there is hardly any form of visual interaction with the terminal, all gates and desks look the same and are schematized by numbers, that are easy to misread and hardly visible in crowded situations. As a consequence of this, passengers tend

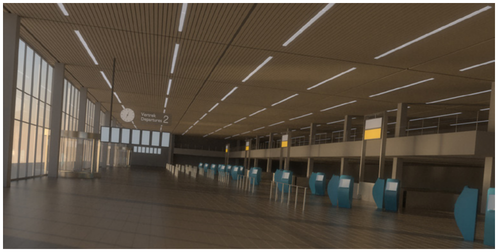

Figure 1 (left)
Current situation of Amsterdam Schiphol Departures Terminal 2

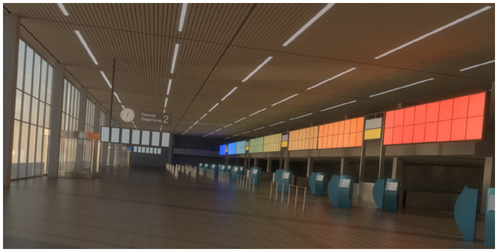

Figure 2 (right)
Proposed situation of Amsterdam Schiphol Departures Terminal 2

to follow others, and therefore end up at the wrong line or, instead of taking an available empty desk, queue for a desk where a line has already formed.

To address these issues one has to speak more directly to the passengers in a more associative, more meaningful and instantly recognizable manner. The information describing where to go should not be clustered and evidently not located in an area so vital for passenger flow. Therefore, in addition to the current situation we will be simulating a scenario in which the numbers of gates and desks are replaced by colors. Travelers will know which color to follow by, e.g. the color printed on their ticket.

Flight information in an airport terminal is only available in a late stadium and might change unexpectedly. Therefore, the colors will be made visible through LED displays. So when information changes this becomes instantly visible for the travelers and they can take the appropriate actions. The number of distinctive colors might be too limited for larger airport terminals. The array of possibilities can be extended by using patterns or symbols. These would also benefit the visually handicapped travelers, such as the colorblind, as it would reduce the dependency on colors.

Simulation

For generating a plausible and reliable estimation of the improvements realized with the design, behavioral characteristics of human travelling have to be implemented. Schiphol Terminal 2 is mostly a business oriented terminal, therefore dealing less with leisure travelling. We therefore assume that the travelers are in a constant hurry and not wandering off from what they see as their shortest route to their destination. From this paradigm we have deduced one of the properties we intend to measure. We refer to this term simply as *annoyance* (see formula 1). At every point in the simulated lifespan of an agent representing a passenger in the terminal, the agent has an intended location to go to. From this seeking target and the current position of the agent, an optimal route can be calculated. However, this optimal route cannot always be followed, either due to passengers standing in the way, or other obstacles on the route of the passenger. Any deviation from the intended optimal path is regarded as unnecessary and therefore introduces additional annoyance. Furthermore, every passenger has an optimal walking speed; these individual speeds differ from agent to agent. A discrepancy between optimal and actual walking speed also increases annoyance levels.

$$A = \sum_{t=0}^{t=e} (2\cos^{-1}(D_{i,t} \cdot D_{r,t}) + | v_{i,t} - v_{r,t} |) \cdot \Delta t \qquad (1)$$

A: Total annoyance level of one agent built up during agent lifetime
t=e: End of agent lifetime
Di,t: Intended direction vector at time t
Dr,t: Realized direction vector at time t
Vi,t: Intended velocity at time t
Vr,t: Realized velocity at time t
Δt: Interval length of simulation time step

Following this definition of annoyance it is impossible for the agents to travel without building up an annoyance level. It is a means for comparing different scenarios.

The case study consists of a comparison of two scenarios:

1. The current situation, where passengers have to look on displays to find the number their check-in desk represents.
2. The proposed design in which travelers are directed by colors instead.

The core of the behavior of the agents consists of a list of locations in the environment to be visited by the agents. Perceptual aspects, such as the field of view and the visibility of colors and numbers from the point of view of the agent, are not taken into account, since the terminal is considered to be reasonably well-arranged and the colors have been strategically placed overhead to guaranty unoccluded lines of sight. A look at this new terminal situation, as illustrated in figure 2, shows that the colors are visible from virtually any point in the terminal. In the proposed scenario the colors are introduced as additional visual cues, but not as complete replacements of the existing displays with flight information. Even in the existing situation not every agent has to look at these displays since they might already know what desk they have to attend. Therefore, the only difference in the two scenarios in respect to the simulation logic is the percentage of passengers looking at the displays with flight information before attending their check-in desk. In the simulation of the current situation this percentage is ninety percent. The proposed scenario has this percentage set at ten percent. The agents are instanced at one of the entrances of the terminal building. If the traveler knows the desk for checking in corresponding to his travel location beforehand, he immediately goes there, waits in line if needed and leaves the terminal when the check-in procedure is completed. If the traveler doesn't know which desk he has to attend, he first has to look at the already mentioned displays with flight information. Furthermore, there is a third group of agents in the simulation. This group consists of the people attending Shiphol Airport, but do not board a plane from the Departures Terminal 2 in which the simulation takes place. Instead, they pass through the terminal in the longitudinal direction.

Implementation

In order to give an accurate impression of the improvements of the design, a behavioral simulation prototype has been implemented. It is based on the OpenSteer framework (Reynolds 1999). The agents in the system detect and avoid collisions both with static obstacles as well as with each other. An extension to the OpenSteer framework has been implemented that enables the simulator to run as a daemon process with network capabilities. The prototype can interact with other software packages and is able to respond interactively to real-time changes in the geometry. Thus, the impact of design changes can be visualized directly without the use of an additional software package to which the design has to be exported: A modeling package can synchronize the geometry in real-time with the simulation daemon and in the modeling package the simulation can be visualized in real time. This way building simulation technology can play an active role in different design stages, instead of just being applied as a validation at the end of the design process.

For a 3d modeling package to be suitable for connecting to the OpenSteer daemon without tinkering with its source code, it must have a scripting language implemented and must allow scripts to run in the background while remaining responsive to modeling input from the user. The open source modeling package Blender supports this. We have developed a prototype that allows simultaneous modeling and behavioral simulation in Blender. It can act as a tool to facilitate rapid shaping of forms based on optimizing pedestrian flow around the object. Instead of iterative design-simulation-evaluation cycles, our prototype provides immediate visual feedback to the designer.

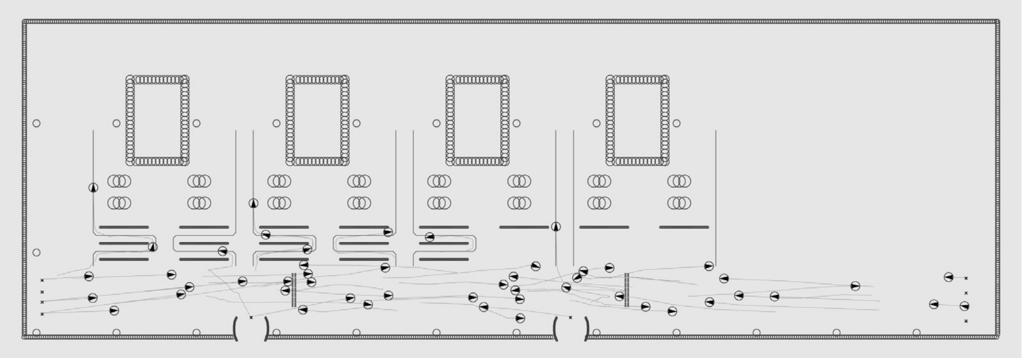

Figure 3
Simulation in OpenSteer

However, in the case study presented here, geometric re-configurations of desks, displays etc. are not considered. But being able to adjust location parameters of the system in real-time allows designers to model re-allocations of flights to different gates and desks. This way, interrupted way-finding and its impact on the overall performance can by studied.

OpenSteer encloses a visualization prototype based on OpenGL. It enables drawing basic two-dimensional representations of the obstacles, the agents, their paths and their trails (see figure 3). However, for the case study presented here, the Virtual Reality framework Vizard has been used for a more lifelike visualization of the results and the communication with the daemon (for a screenshot see figure 4). Furthermore it would potentially enable in a later stadium to do experiments with test subjects in virtual reality.

Currently, the geometry in the modeling application has to be exported manually upon each design cycle and data with certain semantics representing obstacles, starting points and destinations of agents has to be extracted from the actual geometry. The areas where the agents start are modeled manually and since a simulation of queuing is non-trivial, the agents strictly follow a drawn path when waiting in line for the desks.

Other behavioral simulation approaches developed for similar purposes operate at a raster level. The underlying algorithms often are less computationally complex, but have some disadvantages compared to a continuous space approach. A non-discreet approach allows higher precision due to the flexible choice of resolution as opposed to cell-based approximations of parameters. A fundamental advantage is that a vector-based approach allows for the easy extension into three-dimensional simulations, e.g. multi-story simulations and designs with curved surfaces. When visualizing the results, it takes less of an effort to reproduce a realistic representation of the model. This has an advantage when trying to validate the simulated behavior, as it is easier to visually compare it with observed human behavior in everyday life. It can also act as a base for experiments in virtual reality where the implications of design decisions are validated after the reactions of test subjects.

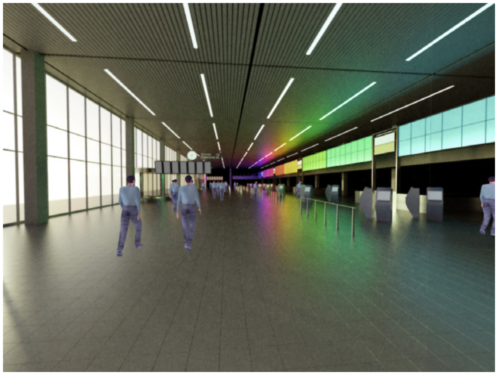

Figure 4
Simulation in Vizard

Simulation results

The simulation of both scenarios proves that the proposed situation outperforms the current situation in all measured areas: The average length of the routes of passengers has been reduced considerably. By introducing the color displays, the need to look at the existing text-displays has been eliminated for most passengers, allowing them to instantly proceed to the check-in desk. The most significant decrease has been reached in the field of annoyance: The decrease in annoyance levels is not proportional to the decrease in passenger route length, but is greater. This shows the effect of cluttering in front of the displays with flight information. Removing this step from the way finding process, e.g. by the design proposed here, results in a significant improvement of the time needed to find one's way and of the overall quality of the terminal. Detailed results are illustrated in Table 1.

Table 1
Example simulation output

Current situation

```
Simulation Finished in 199.3 seconds
Number of agents: 100
Total annoyance level: 3068.36
Total meters walked: 7254.33
Percentage looking at displays: 90%
Passenger annoyance
mean                          30.6836
min                         0.0218139
max                            76.526
std. dev.                      18.914
Passenger route length
mean                          72.5433
min                           14.9951
max                           120.075
std. dev.                     24.8974
Passenger agent lifetime
mean                          60.4181
min                           10.3788
max                           117.875
std. dev.                     19.0937
```

Proposed situation

```
Simulation Finished in 190.105 seconds
Number of agents: 100
Total annoyance level: 1512.76
Total meters walked: 6864.62
Percentage looking at displays: 10%
Passenger annoyance
mean                          15.1276
min                         0.0218139
max                           74.5309
std. dev.                      15.973
Passenger route length
mean                          68.6462
min                           14.9873
max                            119.36
std. dev.                     27.2062
Passenger agent lifetime
mean                          50.9792
min                           10.1088
max                           108.123
std. dev.                     20.6207
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Conclusions and further research

An Autonomous agent-based simulation of pedestrians provides an excellent means for comparing performance aspects of different design solutions. We argue that the agent behavior implemented in our prototype is sufficient to provide valuable indications of human behavior to a designer. In the particular case of rushing passengers in an airport terminal, the erratic behavior of humans (bumping into each other etc.) is mirrored in the abstractions and simplifications of the simulation model. In order to be widely incorporated into the design process, the need for scripting or programming for the end-user should be removed from the process as much as possible. With the prototype of the described in this paper, we have made first steps towards a fully functional, pluggable and extendable solution for agent-based pedestrian simulation. To increase the usefulness of our system, more behavioral patterns have to be generalized and extended for use in common situations.

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