Agent-Based Social Pedestrian Simulation for the Validation of Urban Planning Recommendations

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ABSTRACT
The goal of this project is a deeper understanding of the mechanisms that shape a city with a focus on pedestrian flow. Pedestrian flow reveals the use of space, the capacity and use of transportation and has an impact on the health of people. Movement patterns of pedestrians are a topic in many related fields like transportation planning, computer graphics and sociology. This project augments the simulation of pedestrian decision processes by taking into account the preferences for surrounding factors like additional points of interests and how pedestrians interact along their path with other pedestrians in a social manner. The goal of this project is to analyse urban planning configurations and to give designers and decision makers a tool to measure the amount of people walking and therefore define the health of a society, finding places of social interaction and improving social coherence in neighbourhoods.

KEYWORDS: Urban Planning; Pedestrian Movement; Multi-agent System

1. Introduction

To increase the amount of people walking or cycling to reduce the number of people suffering from cardio vascular deceases is essential (Ministry of Health Singapore: Causes of death: 18.7% Ischemic Heart Disease, 4.8% other Heart Disease). There is a correlation between exercise and cardio vascular diseases e.g. heart failure [1]. Therefore analytical design analysis tools based on empiric input for urban planning are needed to quantify the result. Tools to analyse the city exist but lack dynamic aspects or the results are only understandable by specialists. The simulation is based on a procedural city model the initial demand is generated whereupon a multi agent system (MAS) with competing interests is fulfilling its goal [2]. The processes the agents are undergoing is recorded and written out as a dynamic map to analyse the urban configuration.

2. Background

Based on rectangular grid cells, Cervero and Kochelman [2] showed that there is a relation between Density, Diversity and Design and the occurrence of people walking. With an agent-based method it is possible to recreate this patterns. Agents simulating pedestrians use a polar system with their own position as origin to calculate density and diversity at possible goals to define their path. They react to changes over time and interact with other agents. In the proposed method the pedestrian agents calculates diversity to decide what path to take and therefor increases the footfall. Even though Badoe and Miller [6] showed a significant correlation between extremely high and extremely low density and the occurrence of pedestrian walking the correlation between density and walking in less extreme cases is still under dispute within the research community.

3. System Design

This project uses a procedural city model and augments it with a multi agent system (MAS) consisting of buildings, pedestrians, public transport system and individual transport [7, 8] to simulate the city and the interaction of sub systems (for details see Fig. 2).

3.1 Procedural City Model

To generate the initial demand model a grammar [7] is used to generate a 3D city model and the initial configuration. The 3D City model consists of geometry and the related semantic layer allowing agents to navigate the physical environment and to understand the programmatic content. Additionally the grammar defines the starting states and locations for mobile and immobile agents. For further details, we refer to Aschwanden 2009 [9] where a procedural city model was introduced as base for agent based evaluation [11].

3.2 Agents

The agents can be mobile (pedestrians, cars, buses, etc.) or immobile (buildings, bus stations etc.). This project focuses on simulating the impact of density and diversity as main criteria for decision processes of occupants. Diversity is understood as the location of different functions and amenities in correlation to their respective distance from each other. In this example similar functions are grouped and summed as a measurement of diversity the agents are able to perceive.

The capacity of buildings, defining how many people are living within is defined by specific size, location and function. With a time factor this defines the capacity for absorption during the simulation. In addition to the physical parameters, buildings as source of agents also include socio statistical data that they pass on to the pedestrian agents they emit [7, 12, 13].

Pedestrian Agents: The pedestrian-agents input channels of hearing, seeing and reading the ground and interact with other agents by emitting sound with a specific frequency perceptible to other agents simulating the human sensory system [16] to inform others about their state [17]. The vision of the agent is used to avoid collision with other moving objects [18-22]. The individual experiences of a pedestrian agents use physical aspects and juxtapose them with socio statistical preference distributions for certain abilities, e.g. evaluating how physical demanding the path is in relation to the pedestrian agents' own physical ability. Evaluation can be expanded to the realm of psychological experience like how many times an other agent entered its personal space within a give time frame, making humans stressed [23]. In the following the decision processes for goal finding and social interaction along the path are introduced.

Goal Finding Process: A two-stage decision process is used to define the preferred LRT-Station (Light Rail Train). First, the agent defines which direction is the most promising to fulfil its goals. Then the distance to possible LRT stations is taken into account to decide which LRT station suits the agent's preferences for distance and interest. The following formula describes the measurement for interest from the agent's point of view in respect of preference and distance.

$$\underset{Direction-\alpha}{InterestingLRT} \equiv f_{(P_A,P_{LRT})} = \quad g_{(P_A,P_{LRT},P_{POI})} \bullet I_{POI} \bullet \frac{1}{P_{POI} - P_A}$$

I_{POI} = Interest of Agent A towards a function, where $g_{(P_A,P_{LRT},P_{POI})}$ denotes the weighting function of the agent's position between LRT and POI with $g_{(P_A,P_{LRT},P_{POI})}$ = for -45←←45 else 0 and

The measurements of Weinstein and Bekkouche [23], who defined the mean distance people are walking to LRT stations as 840m / 0.52 miles (1. quartile ←440m, 2nd quartile →440m ←760m and 3rd quartile →760m ←1km), are used to define the willingness of agents to walk in respect of distance.

Social interaction: Walking and stopping are happening sometimes without reasons; in the following we show two cases.

Unexpected Stop: The individual capability is depending on age and fitness, which have not been verified yet, and the function performed. The agents' information of age (Ai) is translated into a numeric value multiplied by a virtual strength (Si) attribute. This total energy (Ai*Si) is reduced with every action according to its tediousness

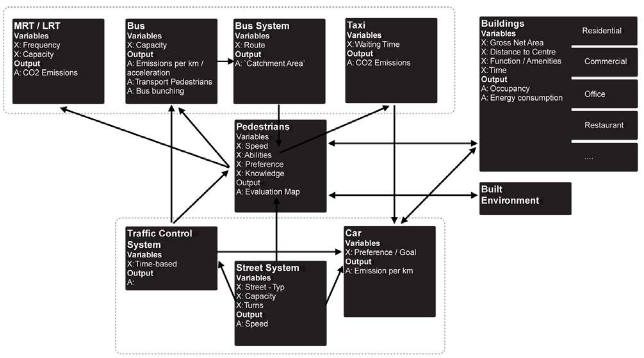

Figure 1: Multi Agent System: Output and variables by type of agent.

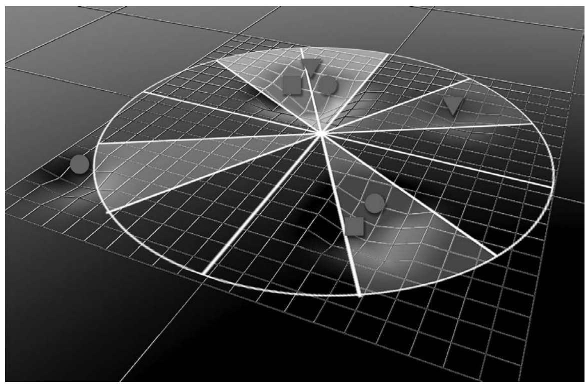
Figure 2: Multi Agent System: Defining the most promising area to fulfil its goals.

and time performed, e.g. walking up the stairs. If total energy value is reaching a low threshold the agent is searching for a resting area or is taking a break heaving implications on the global speed.

Unexpected Social Interaction: For social encounters to happen people have to be at a certain moment within a minimal distance and able to see each other and know each other personal factors, such as "having space to stop", as well as internal aspects, such as "do I have time" are integrated.

4. Results and Test Case in Punggol

Punggol is a 'New Town' still under construction in the north-eastern part of Singapore. It is serviced by the final destination of an MRT Line (Mass Rapid Transit), augmented with an LRT-loop (Light Rail Transit). Within this loop ca. 22 HDB Precincts (Housing and Development Board) have been constructed with each up to ~2000 units. Even though some LRT Stations are having additional functions and amenities, the area is mainly housing. Different allocations of functions are used to demonstrate the impact on the catchment area of each LRT station.

4.1 Setup

To generate the 3D environment, a procedural model was generated from GIS shape files enhanced with a geometrical survey on the site. The number of people occupying the building we defined by the net floor area of each building and its apartment sizes. The procedural model was used to set the initial starting area of the pedestrian agents accordingly. Since the area only has a small number (1.5% of floor area is commercial) of additional functions and amenities a manual method was used to place the individual agents. In total 3 types of pedestrian-agents, 4 LRT-Agents, 10 types were placed to sum up to 2780 agents. The simulation covers 1.33h (1h 20min) time in the evening rush hour (Figure 3 / 4).

Figure 3 and 4 shows the change in movement of the pedestrian thanks to different additional functions and amenities. This leads to less people crossing the street,

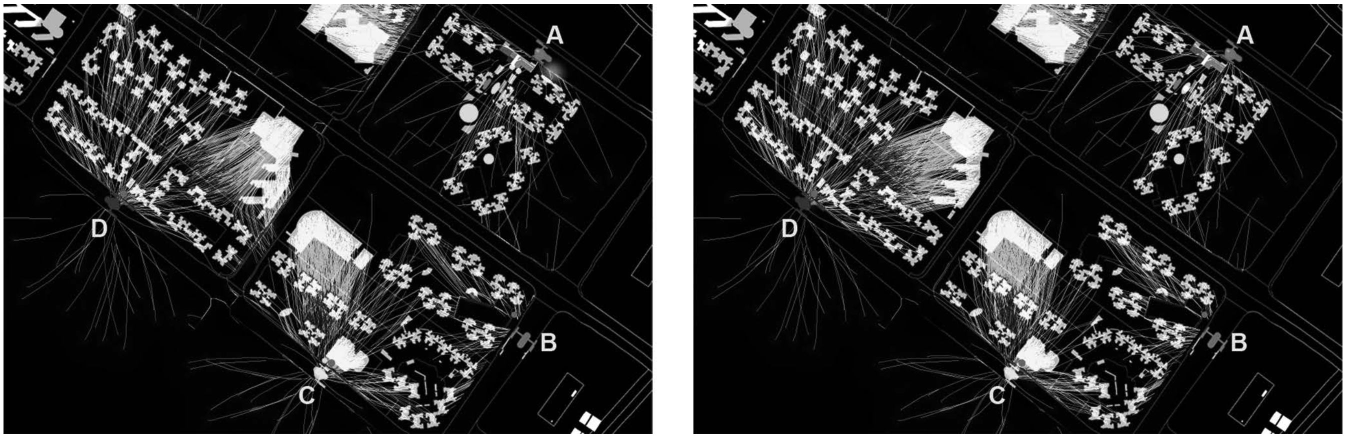

Figure 3: Path drawn by agents, Left: Real Configuration; Right: Optimised configuration.

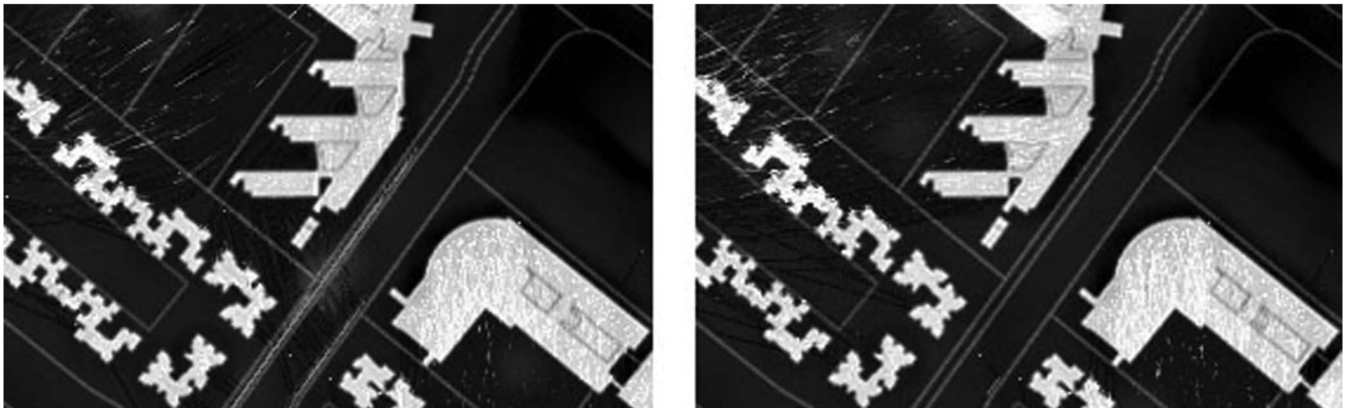

Figure 4: Zoom-in highlighting (red) proximity to other pedestrian agents on the sidewalk of Edgedale plains. Left: Existing configuration. Right: Additional amenities for the secondary school students at the Meridian LRT (see Fig 8. D).

which is also a health risk in case of secondary school students.

5. Potential Future Developments / Results

Pedestrian path finding in Singapore on the city scale is defined by physical borders (see Fig. 5). A boarder is defined as an obstacle that increases the distance for pedestrians by more than the average distance people are walking to the LRT station (832m [24]). This demands the separation of different avenues to explore into global and local ones.

Figure 5: Singapore master plan indicating where the distance for pedestrians to cross natural or manmade obstacles is greater then 300 or 418m.

5.1 Local

The potential avenues of the neighbourhood scale are organized in two directions, functional and physical.

Functional: The results above show the correlation between locations of functions and their direct impact on distance people are walking. Accordingly the following recommendations would increase the distance people are walking.

I) Diversify sub-centres: Options do not mean that at any given LRT-Station needs to offer the same or similar function. With a diversification of the individual stations the users are changing accordingly.

II) Add or remove secondary amenities: Adding or removing amenities already changes the catchment area of the individual LRT Stations – with it the total amount of people can be adjusted to meet the capacity.

III) Create shared spaces: A change in the mind-set of urban and traffic planners has happened from separation of different street users to the creation of shared spaces where cars, cyclists and pedestrians are equal [28], leading to a reduction of serious injuries and a more social interaction.

Physical: Physical changes have to accompany the functional ones.

I) Coherent path system: Each precinct is organizing its path system individually leading to an inefficient rout trough the area.

II) Walk comfortable street crossing: Since Singapore has an aging society planners have to cater to the needs of elderly people where every elevation is difficult to master. Even crossings (crosswalks) or smooth underpasses are more favourable for walking.

III) Reduction of redundant cul-de-sacs: Each precinct provides a road to every building for the collection of trash. These service roads can run parallel, are not connected and could be organized into one.

5.2 Physical Pedestrian Obstacles

In a city the walking path is greatly defined by the physical structure [5] on a large scale and by other occupants as dynamic obstacles avoidance on the small scale. Additional to the obstacles mentioned above a street is also an obstacle since a detour can expand the distance beyond our willingness to walk.

Non Motorized Plan: To avoid further segregation neighbourhood individual "islands" there are two possible interventions, either a coherent network for non-motorized transportation methods or the activation of the street as a public space. The coherent network connects different functions otherwise there is no motivation, e.g. connecting different centres of work, residential and leisure.

6. Discussion

This project has shown that the agent-based simulations not only represent existing configurations, but also can be used to analyse possible interventions and amendments. The pedestrian agents mimicked human behaviour and recreate the movement patterns observed in real world scenarios, in particular the increased willingness to walk in more function diverse environments. Under the assumption that pedestrian agents are a close representation of humans, general recommendations for urban planning and their impact were derived. These recommendations can help to increase the distance people are walking and the physical health of the occupants, making the city to a gym.

7. Acknowledgement

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