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Empiric design evaluation in urban planning

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ABSTRACT

We propose a system to simulate, analyze and visualize occupant behavior in urban environments by combining parametric modeling and agent-based simulation. A procedurally generated 3D city model, with semantic information about the functions and behaviors of buildings, is automatically populated with artificial agents (i.e. pedestrians, cars, and public transport vehicles). In a simulation the built environment and the agents interact with each other. The system identifies empiric correlations between properties such as: functions of buildings and other urban elements, population density, utilization and capacity of the public transport network, and congestion effect on the street network. Practical applications include the assessment of a) bottlenecks, b) public transit efficiency, c) accessibility of amenities, d) quality of service of public transport and the traffic network, as well as e) the stress level and exhaustion of pedestrians. All these aspects ultimately relate to the quality of life within the given urban areas.

1. Introduction

The majority of the world population already lives and works in cities [30]. This influx of new residence puts a lot of pressure on the existing infrastructure, and on the planning of new and the upgrade of existing areas of cities. Cities, like Laos, cannot keep up with building the necessary infrastructure, with the consequence that the quality of life remains insufficient in general. This is partially confirmed by the level of stress experienced by citizens when compared to rural inhabitants. Even though inhabitants of cities are consuming less energy than rural dwellers [40], cities still consume too much energy, produce too much waste and emit too much CO_2 for a sustainable way of living. As a result, we are facing the unprecedented challenge of simultaneously improving the quality of life and sustainability of cities.

Sustainability and quality of life are both complex matters that depend on numerous other, sometimes conflicting, aspects. In the last century, urban planning patterns put emphasis on path and network optimization for motorized traffic and made drastic changes to the structure of the city. These changes not only impact traffic, they also change the allocation of amenities, land price etc. Adjusting one aspect of the city has an influence on different other equilibriums within the city. It has become clear that optimizing the urban layout for pedestrians has a positive effect on the sustainability of the urban environment and the quality of life of its citizens. A shift in the mindset has thus been taking place, with the human perspective shifting into the focus of attention. Taking the interests of pedestrians at heart, we present a robust and efficient method for simulating and visualizing the related performance of different urban environment alternatives. This method combines crowd simulation with procedural city modeling techniques, thereby enabling: a) assessment of the impact of a given built environment on pedestrians, and b) efficient iterative analysis of different built environments. Such tools empower planners with the means to efficiently investigate subtle ways to adjust the urban fabric. Our automated method also offers added value for the entertainment industry. It delivers high quality output imagery through standard production pipelines and decreases the workload to generate the urban layouts. These are simulated as realistic urban environments inhabited by virtual occupants. Traditionally, costs and time needed to produce populated digital urban sets for movies or games are enormous.

The rest of the paper is organized as follows. Section 2 reviews related work in the field of city modeling and urban simulation, Section 3 presents the proposed system for the simulation of pedestrians within a city environment. We also assess the impact of the built environment on pedestrians, and vice versa. We introduce our city model in Section 4 and the semantic data in Section 5. How the city model and the semantic data are affecting the agents is described in Section 6 and the in depth study of their agents is in Section 7. In Section 8 the performance of the proposed system is analyzed through three examples.

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2. Related works

We organized this part in Crowd simulation (Section 2.1), Urban planning (Section 2.2) and Pedestrian movement in urban planning (Section 2.3), and Functional urban models (Section 2.4).

2.1. Crowd simulation overview

Models for crowd behavior have been an active research field since the late 19th century (e.g. see [4]). Today's computer simulation models have a relatively young history. Most relevant approaches have been realized within the last 20 years and are specialized to different fields. A good example is Reynolds [20] flocking method, which uses particle systems and represents one of the most common approaches for simulating group movements.

For multi-agent and large crowd simulation, several techniques have been proposed to animate or simulate large groups of autonomous agents and crowds. These methods can be classified in five groups [22]:

- *Potential-based methods*: Pedestrian-agents are modeled as particles with potentials and forces [9].
- *Flock-like methods*: These approaches were introduced by Reynolds, creating simple rules like separation, alignment, and cohesion for computing the velocities [21].
- *Geometric method*: The aim of these approaches is to compute collision free paths. They either integrate the velocity space or use optimization methods [6,31].
- *Field based methods*: These algorithms generate fields for agents to follow, or generate navigation fields for different agents based on continuum theories of flows or fluid modes [15,27,41].
- *Least effort crowds*: These algorithms compute the paths of crowd agents using Zipf's [39] principle of Least Effort [39]. Recently these have been combined with collision avoidance algorithms and emergency behaviors for a large number of agents.

Brooks [42] provides a comprehensive foundation on which many of the recent agent models and theories are based. He describes many failing artificial intelligence approaches to set up intelligent agents. Musse and Thalmann [14] introduced a more flexible model with hierarchical behavior. Physics and body effects had been described by [9] to simulate escape behavior and panics effectively. In other fields, like robotics [32], safety science [26], and sociology [11], similar approaches have created simulations involving groups of individual, intelligent units. For a more comprehensive description of agent-based pedestrian movement, we refer to Thalmann and Magnenat-Thalmann [12]. Furthermore, Hillier [10] introduced the idea that a city and spaces in general can be divided into components, that can be analyzed as a network of choices and that can be represented as maps and graphs. Penn and Turner [18,19] described urban agents within their space syntax system. Parallel systems evolved in computer graphics to populate urban environments in real-time [18,19,29].

2.2. Urban planning

Current planning methods are based on the experience of the planner and end when the architect finishes the building. This method is insufficient for future needs, changes, and increased pressure on the performance of urban configurations. There is a demand for simulations that incorporate a wider range of scales and interdependencies — from building codes to the level of the entire city. They should help to evaluate and predict the impacts of planning efforts and the changes over time. Single layer optimizations, such as emergency evacuation or traffic simulations, exist in many forms and are widely available commercially. These tools incorporate a very limited number of parameters and either focus on the building performance, neglecting the interdependencies of buildings, or work at the scale of a metropolitan region, using a grid with a scale compiling whole areas of a city.

Recently, there have been approaches to combine behavioral and structural modeling [33,34]. These approaches treat the behavioral state as static input. For example, they try to find the equilibrium between street access and the housing market, an iteration of this loop is still far from being an integrated, interactive system, or dynamic. A closer integration of function, behavior, and state will reduce calculation time and allows a practical integration into the early design phase [28].

2.3. Pedestrian movement in urban planning

There is an effort in transportation planning to include pedestrian movements and to move from car- to pedestrian-oriented transportation planning. However, this development is currently still hampered by a lack of empiric simulation methods. Current methods for pedestrian movement analysis are targeted towards early design stages and thus treat pedestrians more like a statistical input: common parameters are land use and modes of transportation.

According to the classification of crowd simulation methods (Section 2.1), commercial software tools for pedestrian flow analysis tend to either use a particle system with a social force model, neglecting spontaneous decision processes, or incorporate simulated movements of crowds, but this requires knowledge of the position of every source and sink, which has to be manually incorporated.

2.4. Functional urban models

Wegener [37] proposes urban models, in which he defines interactions between different entities such as land use, networks, population, house, employment, and transportation of goods, and then uses the model to compare existing operational models. Wu and Webster [38] developed a model integrating multi-criteria evaluation with cellular automata to simulate land use and its changes. Cellular automata include the special features of traditional urban models and capture the spatial features of the urban fabric. Artificial intelligence (AI) has been adopted to use a knowledge-based methodology, so that models can be constructed in a compositional way, and to provide the ability to simulate decision-making processes of a single agent or a group of agents [3].

Waddell and Ulfarsson broadly define urban simulation as “operational models that attempt to represent dynamic processes and interactions of urban development and transportation” [36]. Their introduction gives a good overview of specific techniques (such as cellular automata or multi-agent systems) that have been successfully implemented in a state-of-the-art urban simulation system, UrbanSim [35]. Traditionally, the tools operate on the level of regular grids considerably larger than individual building lots. More recent approaches overcome the rigid grid-cell model by taking more refined scales into account, typically starting from parcels to zones [43].

3. Overview of the proposed approach and contribution

In Aschwanden et al. [2], an occupant simulation method was introduced, which is extended by the present work. The procedural modeling technique, on which our urban model is based, was initially presented by Parish and Müller [16,17] for the modeling of cities. Muller et al. [13] extended it for the modeling of buildings, and it has been applied to the context of urban planning by Ulmer et al. [25] and Halatsch et al. [7,8]. Generative city models not only allow adjusting and updating the physical representation of the city and its street layout or a single building, but they also incorporate metadata about