ASSESSING URBAN MICROCLIMATE USING MULTI-AGENT SIMULATIONS: A NEW APPROACH TO ANSWER AN OLD PROBLEM?

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Abstract

The re-discovery of the urban environment as an important component of daily life induced an increased interest in methods for assessing the quality of open spaces with respect to their contribution to the quality of urban life. A wide range of studies ranging from field experiments up to the application of numerical models have been conducted in order to understand and predict the interactions between the urban design, local microclimate and human comfort. Unfortunately, like in most other cases in which individual human decisions are involved, the relationship between the stimulating factors and the observed behaviour patterns are far from being trivial.
Using the technique of Multi-Agent simulation, new insights into the complex interactions between microclimate, the thermal comfort of an individual pedestrian and the emergent pedestrian behaviour patterns can be obtained. In this paper the outline of the climBOT model system and its possible application to assess urban microclimate is presented.

Key words: Multi-Agent Simulation, Urban Climate, Pedestrian behaviour, Thermal comfort, Biometeorology

1. INTRODUCTION

At the beginning of the 21st century the global trend of urbanisation remains unstopped having strong impacts both on the environment and on the quality of life of the citizens. The limited space available leads not only to an increasingly high density usage of urban areas but also to an urban sprawl into regions normally not meant for human settlement like desert settlements or tropical mega-cities. Building up cities in such hostile regions raises the question, how the urban environment could be designed to offer the best possible climate conditions to the citizens. But not only extreme regional climate conditions can cause hostile outdoor environments, unpleasant local conditions can also be generated by bad urban design leading to undesired phenomena such as wind gusts caused by jet effects from the building constellation, high air pollution or unpleasant thermal conditions in general. Regardless if the first, the second or both reasons apply, as a matter of fact it can often be observed that urban open spaces fail to offer adequate environmental conditions to be attractive locations used by citizens.

Planers and architects wishing to maintain or increase the quality of urban life by promoting the usage of open spaces are facing difficulties in assessing the effects of different urban design ideas on peoples comfort and behaviour. In the context of urban microclimate, this problem can be divided into two sequential challenges: Firstly, the effect of urban design on local microclimate has to be estimated and, secondly, the consequences of this microclimate on the behaviour of the potential users of this urban structures need to be assessed. In this paper we will focus on the second half of the problem.

1.2 Assessing outdoor microclimate

Assessing an outdoor location with respect to microclimate basically means to answer the question, whether the majority of the potential users will be pleased by the offered climate conditions or not. More concrete, it has to be clarified,

- how the users feel under the given conditions (in particular thermal comfort, wind comfort etc.)
- how those feelings will affect their behaviour within the outdoor structures, and
- if the outdoor design, the thermal preferences and the behaviour of the users fit together or not.

If we neglect extreme situations, in which the hostility of the environment is obvious, it is clear that urban climate itself does not posses properties making it a *good* or *bad* climate. The question, whether someone is pleased by the local climate or not, is basically a question about what this single person expects from the climate he or she is walking in. These expectations are, of course, a mixture of general preferences and short-term needs that may vary with respect to the actual physical (heat balance), physiological (thermoregulatory strain), and psychological (e.g. work or leisure) state of the subject. This circumstance produces a number of difficulties and uncertainties in the search of objective assessment parameters, adding to the already complex climate conditions themselves.

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Different biometeorological indices such as PMV, (OUT-)SET*, ET* or PET (see ASHRAE, 1992; de Dear and Pickup, 2000; ISO 7730, 1994; Mayer and Höppe 1987 for example) have been developed in the past to help planers and researchers to relate the local meteorological conditions to the average thermal sensation experienced by the pedestrians. Unfortunately, these models cannot answer the question, how these sensations will influence the pedestrians behaviour and thereby their distribution over and usage of the offered space.
In addition, due to the local approach used in the assessment process, it is not possible to take non-local or non-stationary effects into account. Those dynamical effects can significantly influence the individual's assessment of the local climate situation, especially if the climate conditions experienced before have caused thermal discomfort situations. In these cases, local conditions promising the contrary thermal effect are favoured, although they might lead to another thermal discomfort on a longer term basis ("alliestesia effect")

Recent studies have shown significant differences between the thermal assessment of an open urban space based on static indices such as PMV and the results obtained by empirical methods such as interviews with the actual users of the urban space. For example Nikolopoulou (2002) has shown in the framework of the EU project RUROS (*Rediscovering the Urban Realm and Open Spaces*) for case studies in Athens (Greece) that a PMV based assessment of an outdoor space suggests 51% of the users of an open space being in hot discomfort whereas interviews actually showed a significant lower percentage of only 17% people feeling that way. In addition, 28% of the people interviewed felt a cold discomfort under local climate conditions whereas the PMV results only indicated warm discomfort conditions.

The discrepancy between the calculated and observed thermal sensations as well as the mentioned conceptual drawbacks of local indices in general raise the question, if the usage of alternative modelling techniques could help to obtain more realistic information and is an appropriate tool to understand and predict the influence of microclimate on pedestrian behaviour.

2. Multi-Agent Simulations as a tool to assess microclimate

The perception and the assessment of the urban environment is a process taking place on the level of the individual pedestrian. In order to make conclusions about the average quality of an area, the individual assessment data must be collected and summarized into statistically representative indicators. In traditional model concepts such as the biometeorological models mentioned above, the step of estimating the effects on microclimate on the individual pedestrian including the individual assessment is skipped and a direct link is drawn between the properties of the location (microclimate) and the assessment of the location (indicator).

So-called Multi-Agent (MA) models are based on a different concept. They aim to reproduce complex behaviour patterns by breaking the simulated system down to the individual actor (agent) which is following a limited and, compared to other model concepts, relatively simple set of behaviour rules and activity options. Contrary to traditional models, where the macroscopic behaviour rules must be known as model equations a-priori to design the model, Multi-Agent systems allow to discover new rules and mechanisms by simulating the behaviour of each single agent. Macroscopic effects and the overall dynamic of the system is developing during the simulation through iterative application of the microscopic behaviour rules given to the agents and their interactions between each other and the environment.

Using the concept of Multi-Agent models to assess the quality of urban open spaces means that each individual person visiting the area of interest is represented by a single agent with individual personal properties (age, clothing,...), preferences (preferred climate conditions) and aims (movement targets, activity plans). While the agents are moving around in the virtual environment, they are experiencing different microclimatic conditions, they have to compete for space with other agents and they can select their optimal routing to their targets depending on their actual needs and goals. One of these goals in the framework of the MA system "climBOT" presented in this paper is to maintain or reach an acceptable thermal comfort state. If an agent is in thermal discomfort (e.g. hot discomfort) it will avoid walking through areas that will keep or increase this discomfort (sunny spots) whenever possible. On the other hand, walking routes promising to decrease the discomfort level (shady places) are attracting the agent.

2.1 Possible results provided by Multi-Agent Models

Analysing results from MA models such as the climBOT model is similar to the handling of empirical data. The amount of data produced is impressive and must be compiled with respect to the questions asked to the model. One way this synthesis can be made is by summarising the data provided by agents visiting an area of interest simulating a kind of "virtual interviews" where the agents provide for example their actual thermal state or level of satisfaction. These method would correspond to a high degree with the methodology of field interviews. Another approach is to analyse the usage pattern of areas (frequentation, average state of visiting agents,…) to make conclusions on the acceptance of the analysed area or to obtain information about the demands of the visitors in the area. The knowledge of such a profile of demand is not only interesting for urban design analyses but can also have a major impact on economic decisions such as the optimal localisation of shopping facilities.

3. The climBOT model system

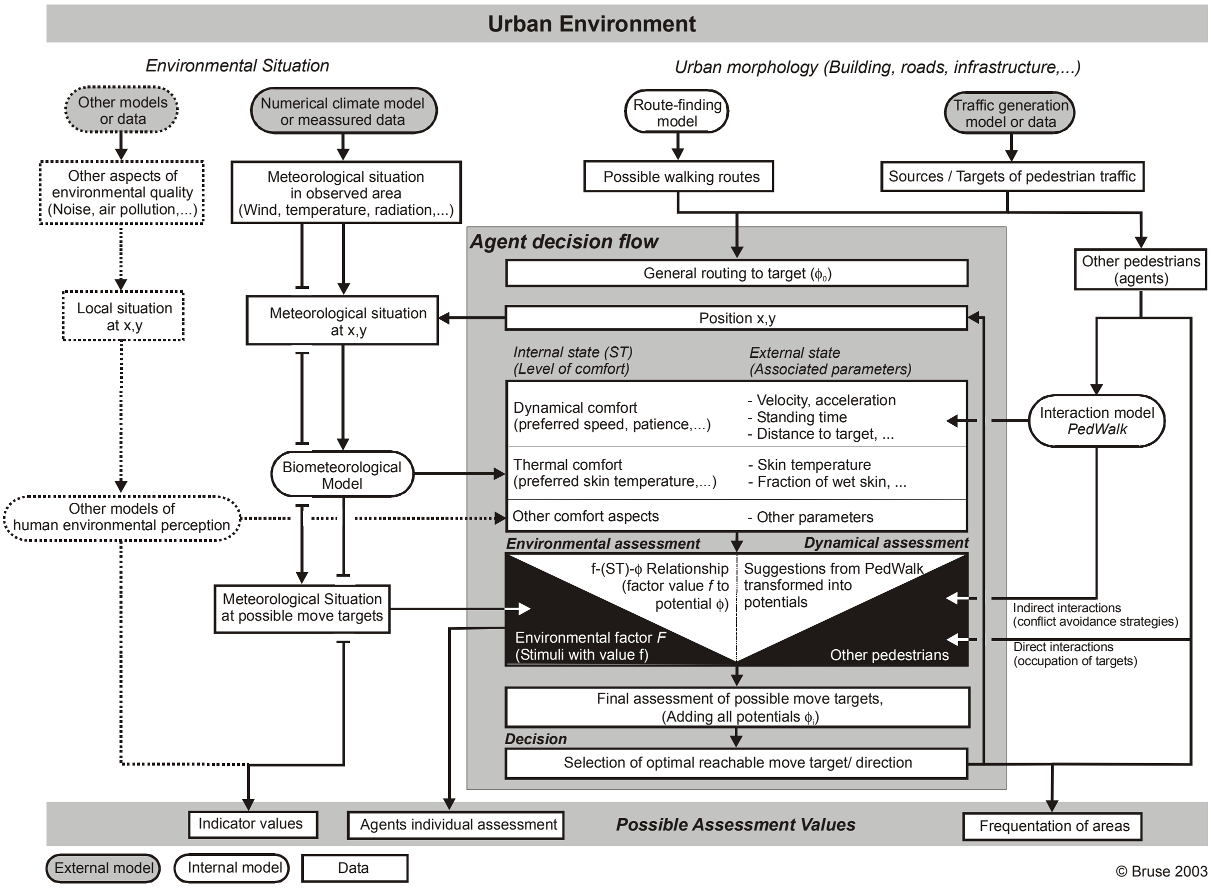

Figure 1: Overview over the climBOT system

3.1 Overview and Basic Properties

The climBOT model is based on a two-dimensional horizontal model grid with a typical cell size of 0.5 to 1 m representing the spatial structure of the simulated area including the position of buildings, the position of sources and targets of pedestrian traffic as well as additional information about the "walkablility" of ground surfaces.
The meteorological situation is defined in terms of air temperature, radiative temperature, vapour pressure and wind speed and –direction data for each of the grid points. The climBOT system is designed to operate together with the microscale climate model ENVI-met (Bruse and Fleer, 1998) providing the required data, but other sources of data (models or measurements) can also be used.

The central concept of the model to decide whether a grid cell is attractive for an agent or not is to assign different **potential values (ϕ)** to the cells. Depending on the number of included factors several potentials add up to the final "value" of a grid cell. The higher the potential, the more attractive is the grid cell for the agent.
The climBOT model calculates forward-in-time with a time step depending on the speed of the fastest agent and the smallest grid size. After each time step, the positions of the agents are updated, the biometeorological state of each agent is calculated and, if necessary, the agents' assessment of the grid cells is adjusted to the thermal state of the agent.
Figure 1 gives an overview over different sections and modules used in the climBOT system. In the following sections, the general model design is described more in detail seen from the perspective of an climBOT agent (gray central box in Figure 1)

3.2 Model design as seen from the single agent

The movement decisions of an agent are based on the primary goal to reach a given target point inside the model area. The **Route-finding model** is responsible for providing the agent with the required information about the optimal route to this target, taking into account non-passable structures such as buildings or water but no other temporary information such as the position of other agents competing for space. The result of the route-finding model is a first basic potential for each grid cell (ϕ_0) describing the “quality” of that cell for leading the agent closer to its desired target. The higher the potential is, the closer the grid cell is to the target cell. Using this basic potential, the agent can decide locally, which of the eight adjacent grid cells will bring it closer to the target and which lead further away. The route-finding is implemented using a modified Bellmann-flooding algorithm that estimates, similar to the better-known A*-method, the total “cost” of the way from any grid to the target cell by adding up the costs of all grids along the way.

The **PedWalk model** takes care of the dynamic interactions between the agents themselves. This includes acceleration or deceleration to avoid collisions, the overtaking of slower agents or other deviation maneuvers. The suggestions of the PedWalk model are also expressed using potentials making grid cells more or less attractive than others. For example, grid cells very close to other agents are getting a small negative potential resulting in a certain distance between the agents as long as adequate other routing options exist.

The **Biometeorological model** simulates the thermal complex of the agent. The model is based on a 2-node approach similar to the model presented by Gagge (1986) or Höppe (1985). Based on the actual position of the agent, the local meteorological data are used to update skin temperature, core temperature, sweat rate and other parameter of the human thermal complex. Due to the detailed spatial data available, the effect of relative wind speed and walking velocity on thermal clothing insulation and water permeability (Parsons *et al.*, 1999) could be included in the model as well as a detailed calculation of the sweat mass on the skin.

The task of the **Environmental assessment** step is to transform the value f an environmental factor F (for example F=”*Radiative Temperature”*) into a potential ϕ depending on the internal state ST of the agent. If the internal state ST of the agent is shifted out of the neutral zone, factor f will create a potential ϕ different to zero. In hot thermal discomfort, high f values (sunny) will create negative potentials (not attractive) and low f values (shady) create positive potentials (attractive). The mapping function f-ST-ϕ is realised with simple geometric functions requiring only the definition of individual threshold values. The internal state ST is obtained using adequate biometeorological indices such as the actual skin temperature in the case of assessing the radiative temperature conditions.

In the final **Decision process** all available potentials for the eight adjacent grid cells of the agents position are summed up. After checking the availability of all grid points (they might be occupied by other agents at the time of decision), the agent selects the grid cell offering the best available potential increase as next movement destination. After reaching the final target, the agent is either selecting another target or is removed from the model.

Conclusions

In this paper the basic concept of the Multi-Agent Model climBOT is presented. With this model, a new modeling approach is designed to assess the microclimate conditions of urban open spaces by focusing on the individual actor (pedestrian or agent) rather than on the local meteorological situation. This paper aims to present the outlines of the model idea and to initiate discussions on that approach, the model itself is only in a prototype stage at the moment. For more information please refer to www.botworld.info.

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