Landscape and Urban Planning 100 (2011) 386–389

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Integrated urban microclimate assessment method as a sustainable urban development and urban design tool

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ARTICLE INFO

Article history:
Available online 3 March 2011

Keywords:
Integration
Urban climate research
Sustainable urban development
Urban design tool

ABSTRACT

In the past decades, urban heat island (UHI) phenomenon in the city and its corresponding issues including the mitigation methods have become the main research topics in the area of urban climatology. Researchers have conducted various investigations and measurements in the urban environment. Prediction models such as impact mitigation strategies, urban air temperature predictions, improved weather forecasting and air quality forecasting have been developed as a result. With the current issue of sustainable urban development in the cities, urban planners are beginning to look into different aspects of urban climatic parameters and incorporate them as the design parameters. However, it is rather difficult for the planners to attempt to design without engaging the urban climate scientists. Presently, Geographical Information System (GIS) is a platform commonly used in various geographical related research and applications, including those relating to urban climate research, as it can be used to analyze different urban climatic parameters. Although it is, by all standards, an appropriate urban design tool, urban planners tend not to embrace this technology. This paper shall present an idea to overcome this challenge by means of developing a user friendly urban design platform that takes after GIS. This paper will also discuss the plan for advancement of the urban design tool from the current situation to the future.

1. Introduction

Urban populations have grown significantly over the past two centuries, from 3% in 1800 to 14% in 1900 and 47% in 2000. Based on a United Nations estimate, 61% of world's population (up to 5 billion people) will live in urban areas by year 2030 (Oke, 1987). Given this trend, the Urban Heat Island (UHI) has become a global phenomenon as cities attempt to accommodate increasing demand for housing, commercial development, recreation space, and other uses which in turn increases the energy consumption of buildings, alters urban climatology, modifies urban wind patterns, and increases the concentration of air pollutants.

Urban climate researchers have made UHI and its mitigation strategies the main research focus in recent decades. Several studies acknowledge the influence of urban form on thermal comfort, urban temperature, and the urban heat island intensity. As a result of UHI studies, numerous prediction models have been developed for evaluating the effectiveness of impact mitigation strategies, predicting urban air temperature, and forecasting weather and air quality.

Currently, UHI study methods are categorized as multi-scale phenomena and include observational approaches such as field measurement, thermal remote sensing, and small-scale modelling; and computer simulations where energy balance modelling and computer fluid dynamics (CFD) are commonly used (Mirzaei and Hahighat, 2010). As a result, more than 30 urban land surface prediction models have been developed with different approaches (Grimmond et al., 2010). These models vary from simple representation of urban environment to a 3D geometry of buildings with varying heights and material characteristics. In order to make use of these prediction models, users have to key in different parameters, which usually confine the urban climate knowledge domain, for example, anthropogenic fluxes and turbulent latent heat.

Current priorities placed on sustainable urban development have encouraged urban planners to examine the various parameters of urban climate modelling and incorporate them into planning and design efforts. But while they may understand the importance of interactions between urban morphology and urban microclimate condition, they lack basic knowledge of urban climatology. Engaging urban climate scientists to conduct assessments and provide feedback has helped inform design and planning efforts, but to date the design process has been largely decoupled from the impact

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doi:10.1016/j.landurbplan.2011.02.012

assessment and analysis process. Urban climate scientists need to improve communication with the urban planners, architects and engineers (Yow, 2007), Mills (2006) proposed a conceptual method that puts urban climatology knowledge at the center of design process with different scales; buildings, building groups and settlement.

Geographical Information Systems (GIS) provide a common platform for various geographically related research and applications issues, including those relating to urban climate research. As such, GIS can be used to analyze different urban climatic parameters, for example, urban climatic mapping technique. However, GIS is still lacking in its capability as a user-friendly urban design and planning tool. This paper presents a means to overcome this challenge through development of a user friendly urban design tool for climate assessment built on a GIS platform. The Screening Tool of Estate Environment and Evaluation (STEVE) will be one of the examples used for the discussion. This paper also discusses the plan for advancement of the urban design tool from the current situation to the future, in parallel with more mature design tools at the building level, such as the Building Information Modelling (BIM).

2. Current urban climate analysis tools and methods

2.1. Nation/city-wide level climatic mapping

Among the various UHI study methods mentioned above, the urban climatic mapping method (UC-Map) has been found to be very useful for urban planning purpose since it integrates various urban climatic parameters with urban planning considerations. While this method has been used in Germany since early 1980s, its wider adoption by other cities has been slow because planning and urban climate research arises out of different knowledge domains. Meteorologists know little about the planning requirements that consider urban climate factors, while urban planners have little understanding of the types of climate data that can be provided for their planning purpose (Matzarakis, 2005). The mapping method compiles meteorological, land use, building footprint, topography, and vegetation information; analyzes their effects on thermal load and thermal comfort; and spatially classifies thermal impacts into several categories (CUHK, 2008). Map results show that the interaction between urban structures and climate becomes more prominent when the city is not located in a flat terrain. Urban ventilation or wind paths within the city will also change according to the topographic condition. Therefore, it is not only the land use and the urban structures that are considered in the map, but also the topography and its influence on urban and rural ventilation.

2.2. Estate level climatic mapping

Urban climatic mapping at the estate (neighbourhood) level provides a more detail climatic condition, i.e., urban air temperature, as compared to an urban climatic map at the city level, as it usually has the scale of 1:5000–1:100,000 with the resolution of 100 m grid. Known as a temperature map, its methodology was developed based on the findings that urban air temperatures are closely related to land uses (Jusuf et al., 2007), which in turn are related to urban morphology characteristics, such as sky view factors, greenery condition, thermal mass of the built environment, and building materials (Jusuf and Wong, 2009). While urban planners are not able to modify the overall climate condition, they can modify urban morphology conditions. With the temperature map, planners are able to analyze the impacts of their design to the environment.

The Screening Tool for Estate Environment Evaluation (STEVE) was developed with the motivation to bridge urban climatic research findings, especially air temperature prediction models, with urban planning and design efforts. STEVE is a web-based application that is specific to an estate and it calculates the T_{min}, T_{avg} and T_{max} of a point of interest for the existing condition and future condition (proposed master plan) of an estate. With STEVE, urban planners are able to calculate the predicted air temperature easily based on their designs and do some design changes when they encounter hotspots. Therefore, urban planners do not need to engage scientist to assess their designs and thus can expedite the design process without compromising the emphasis on the sustainable urban design.

3. Prospects for an urban climatic analysis tool

To develop a sustainable city, it is not sufficient to focus only on green building designs. Sustainable designs must be looked at on a wider scale. The prospect of an effective urban climatic analysis tool lies on how to analyze the interaction between buildings and their surrounding environments as an integrated urban design process. This interaction cannot be separated from the geographical context, in which GIS has the strongest capability. Dangermond (2009) uses the term GeoDesign, which brings geographic analysis into the design process, where initial design sketches are instantly vetted for suitability against a myriad of database layers describing a variety of physical and social factors for the spatial extent of the project. The advancement of the urban climatic analysis tool from the current situation to the future can be categorized into four parts, which are shown in Fig. 1 and are explained in the following sections.

3.1. Integration of 3D modelling with the GIS simulation platform

The current GIS platform can be considered as two or two-and-a-half dimension instead of three dimension interface, where the X and Y coordinates are displayed as graphics and the Z coordinates are stored as the attributes of the objects, such as maps and terrain models. As compared to the computer-aided design (CAD) and/or building information modelling (BIM) software, both have different functions, have their own strengths, and work at different scales. The CAD and BIM tools are mainly used in the Architecture Engineering and Construction (AEC), while GIS is meant for geospatial analysis.

The integration between these two platforms is the next direction. There should be integration between the geographic data and spatial modelling into the design process. The main challenge is at the information workflows or data interoperability of the two domains. Interchangeable data formats among various 3D modelling approaches becomes critical. The Industry Foundation Classes (IFC) has established a standard for it. However, the building model in CAD/BIM is usually not geo-referenced to the location where the building sits. It will be beneficial if in the early stage of the design process contextual information is included as part of the building design, such as terrain, surrounding buildings, roads, utilities, and environmental issues. A building often relates to the other surrounding buildings in terms of design and operation which might include the design of inter-building tunnels or skywalks or connection of other infrastructure. Inclusion of geospatial referencing systems in BIM will facilitate the integration of multiple BIM models for precise design.

3.2. Integration of different climate data into an integrated simulation platform

The urban boundary layer microclimatic condition is very dynamic and complex, either due to the macro climatic conditions or urban morphology conditions. Any urban morphology changes

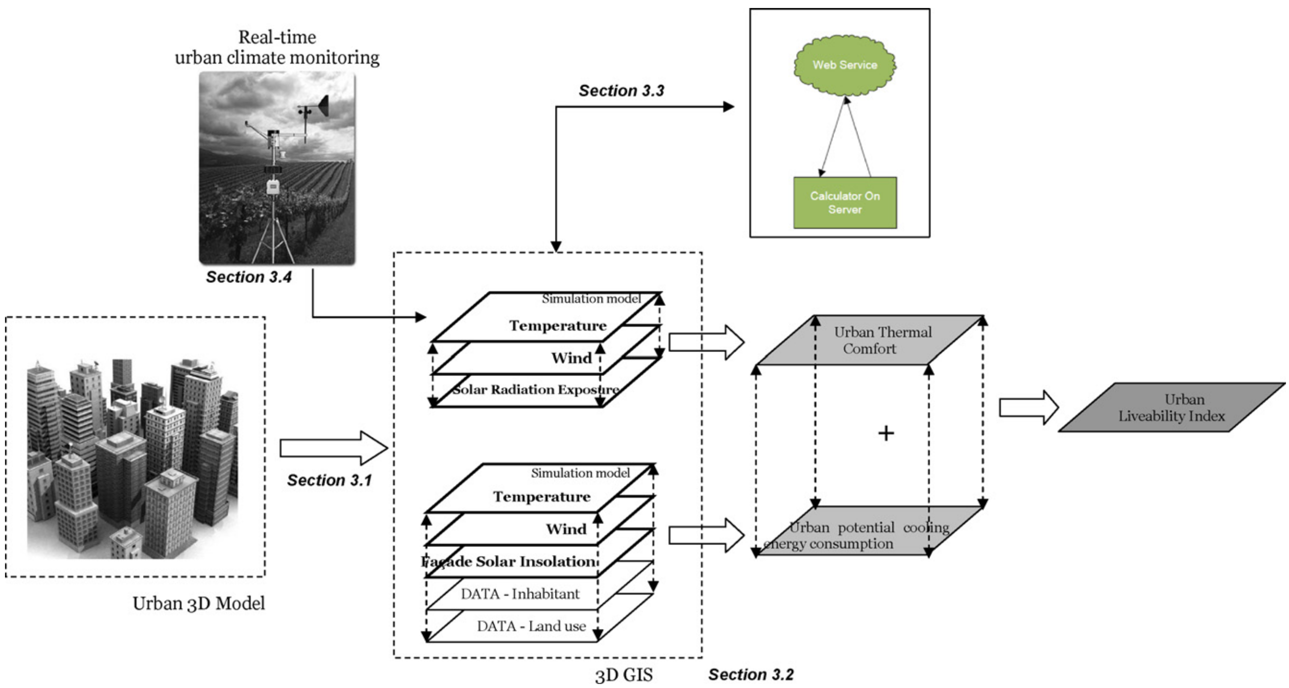

Fig. 1. Workflow concept of the integrated Geographical Information System (GIS)-based urban environment assessment tool.

in an area will result in a change in the surrounding air temperature, air movement pattern and solar radiation exposure. These parameters are currently obtained from different simulation software, for example, air temperature by STEVE in GIS platform, wind pattern by Computational Fluid Dynamics (CFD) and solar radiation exposure by Ecotect.

Ideally, in the context of sustainable urban development, urban planners should analyze these parameters all together and obtain the optimum results during the master planning process. Integration of different simulations result into a common platform or developing simulation models in a common platform becomes critical. By doing this, the problem of segregation between different climatic data will be resolved.

The goal is to generate an Urban Thermal Comfort map where temperature, wind and solar radiation exposure layers are analyzed together inside the GIS platform. Planners can then analyze expected comfort levels and make changes in the design at the locations where it is uncomfortable. Meanwhile, the 3D cumulative building facades solar insolation layer will be integrated with the earlier simulated temperature, simulated wind, inhabitant data, and land use data to develop an urban potential cooling energy consumption map. Finally, the Urban Thermal Comfort map and the urban potential energy consumption map will create an urban liveability index.

3.3. Integration of the simulation platform with the web server as a collaborative design tool

The integration of 3D CAD/BIM modelling with GIS platform explained in Section 3.1 will be optimal if it can be done through a web server since designing a complete city master plan is a collaborative and multidisciplinary task. This effort is similar to the idea in the SEMPER-II (S2) project (Lam et al., 2006), which developed an Internet-based building design and performance simulation environment, but at building scale as compared to a neighbourhood or city scale. The challenge now is even greater than the S2 project, because there must be a web services architecture integrating the workflows and information resources of CAD/BIM with GIS. The Open Geospatial Consortium (OGC) is currently looking into this aspect (Cote, 2007). Once the interoperability between platforms has been established through a web service, the city scale simulation will then be developed within this web service. Urban planners will be able to obtain relevant planning information, for example, from government agencies or geo-engineers, through this web service and proceed seamlessly with planning, impact assessment, and design submission.

3.4. Integration between real time urban climate data and the simulation platform as a boundary condition of the simulation scenarios

The real urban boundary layer climate data can be considered as non-existent since most of the meteorological data of a city is gathered at the airport located outside of the city. Using this meteorological data as the boundary condition of a simulation study at the city center may lead to an incorrect prediction result. Researchers usually conduct a field measurement for a certain period of time if the time permits, otherwise, it will just be an instantaneous measurement before running the simulation study. However, this method will no longer be sufficient if the simulation is needed as part of the design process and its iterations.

With the issue of sustainable development and climate change, it is the urban regulatory bodies that are encouraged to invest in an urban climate measurement network integrated with, for example, traffic cameras, and make the data available to the public. Over a long period of time, this urban climate data will be useful in various ways, not only for the immediate information of city's microclimate condition to the public, but also for research and policy making, such as for the study of the microclimate changes of a city. The simulation platform will then be connected to the real-time urban climate data through a web service and users will be able to select the nearest station as their boundary condition inputs.

4. Conclusions

The integration of urban planning and design tools with urban microclimate assessment tools is a complex endeavour but one with a promising future. This integration will integrate urban climatic assessment as part of the urban design process. Urban planners will be able to assess the impact of their designs, i.e., the change of urban morphology, to the urban climatic condition simultaneously without separately engaging scientists.

This integrated urban microclimate assessment method can be achieved through several stages. The first stage is the integration of different climate data into an integrated simulation platform. The second stage involves the integration of 3D modelling with the simulation platform. The third stage is the integration of the simulation platform with the web server as a collaborative design tool. And finally, the integration between real time urban climate data and the simulation platform as a boundary condition of the simulation scenarios.

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