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Characterization of the urban microclimate by the modelling of urban planning policies in France

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Abstract. With the increase of Urban Heat Islands (UHI) and the effects of global warming, cities will face challenges in anticipating these phenomena. However, the complexity of urban development within the framework of urban planning policies, makes difficult for urban decision-makers to anticipate the Urban Heat Islands within their territory. In this paper, we propose a methodology to assess the impact of urban planning policies on Urban Heat Island. Thanks to a coupling of 2D urban growth model, 3D constructability model and urban microclimate simulation, this tool will make it possible to visualize the impact of urban planning decisions on urban form and on Urban Heat Island.

1. Introduction and research context

For many years, cities have faced multiples issues. They are increasingly mineral, dense and extensive in response to the increase in their population and the concentration of activities. These urban and demographic challenges lead to a degradation of the urban microclimate marked by an increase in urban temperatures [1]. This phenomenon, better known as Urban Heat Island (UHI) is increasing in intensity, aggravated by the effects of global warming.

Urban Heat Islands are an important subject for urban decision-makers and the scientific community because they lead in particular to increase energy consumption, vulnerability of infrastructures and inhabitants in hot periods causing health problems or even mortality [2]. Today, different methodologies have been developed to anticipate Urban Heat Islands [3]. These strategies require knowledge of urban parameters, but mostly of urban planning policies which are at the origin of the urban forms.

However, if the consideration of urban parameters is widely documented. The integration of planning policies remains a challenge in studies and tools which aims to study and anticipate Urban Heat Islands [4].

Our work is, therefore, in the continuity of these issues. Our aim is to present a methodology which integrates urban planning policies in a tool and takes into account urban microclimate simulation in order to assess their impacts on Urban Heat Islands. Particularly, in this paper, we present the regulatory-climate approach used to characterize urban forms, the models used and we will conclude on the development prospects of the tool.



2. Methodological approach

The formulation of urban planning policies and urban development projects is a complex process which must take into account a set of urban, economic, social, environmental and climatic issues. At present, the causes of the intensification of Urban Heat Island are well identified in the scientific literature and well-known to urban stakeholders. However, there is no tool to anticipate Urban Heat Islands as part of the development of urban planning policies.

The general objective is to allow the implementation of studies of territorial development and Urban Heat Islands by associating model of urban growth, model of built configuration with a microclimatic model.

We propose a methodology allowing, thanks to a regulatory approach resulting from urban planning, to design a tool for urban stakeholders which uses both a regulatory approach and a climatic approach to characterize and assess the urban area. We have chosen to use the SLEUTH model, which identifies locations suitable for urbanization, SimPLU, which models the constructability of 3D built forms while respecting local planning constraints and SOLENE – microclimat which simulates the climatic behavior at a district scale. This coupling meets the need for tools to anticipate Urban Heat Island within the framework of urban planning policies; to which extent must the Local Urban Plan (Plan Local de l'Urbanisme, PLU in France) be modified to reduce the impact of Urban Heat Islands on the population?

2.1. Regulatory – climate approach of urbanism

In France, urban planning policies are used to manage and govern the development of territories. The Local Urban Plans are the regulatory operational tools put in place to control the town planning and urban development at a municipal and inter-municipal scale since the ALUR law of 2014 [5].

These tools consist of five mandatory elements: presentation report, planning and sustainable development project, planning and programming guidelines, urban planning regulations and annexes.

In this work, we focus on the resources of urban planning regulations. These documents concretely implement the orientations of the urban planning and development project. These regulations are broken down into 16 articles. All on them constitute a set of rules fixing land uses, architectural, landscape aspects and urban form of the territory. They must be respected in the context of any construction or renovation project on a parcel of the territory.

These articles are governed by the French Urbanism Code. They define the regulatory urban form of a territory. However, their content is free, which allows a great diversity of expression of urban rule within each territory.

Table 1. Articles of urban regulations of Local Urban Plan and causes of Urban Heat Island

Urban form elements	Article	Title	Urban parameters influencing UHI	Causes of UHI
Building	1	Forbidden or allowed land uses	Activities	Anthropogenic heat
Building	2	Land uses subjected to particular rules	Activities	Anthropogenic heat
Road and public area	3	Access and roads	Road area	Increase in waterproofed area
Road and public area	4	Technical networks	Urban porosity, roughness and sinuosity	Disruption of urban ventilation
Parcel	5	Minimum parcel area	Urban porosity, roughness and sinuosity	Disruption of urban ventilation
Road and public area	6	Building location related to road and public area	Urban porosity, roughness and sinuosity	Disruption of urban ventilation
Parcel	7	Building location related to parcel borders	Urban porosity, roughness and sinuosity	Disruption of urban ventilation
Building	8	Building location related to others building	Sky view factor	Disruption of heat exchange
Parcel	9	Building footprint	Surface density	Increase in waterproofed area
Building	10	Building maximal height	Urban porosity, roughness and sinuosity	Disruption of urban ventilation
Building	11	Exterior appearance	Sky view factor	Disruption of heat exchange
Free space	12	Parking	Albedo and inertia	Disruption of heat exchange
Free space	13	Free space, vegetation and protected woods	Air conditioning	Anthropogenic heat
Parcel	14	Floor area ratio	Road area	Increase in waterproofed area
Building	15	Energetic and environmental performances	Green spaces and vegetation	Decrease in natural spaces
Road and public area	16	Communication network and infrastructures	Total built density	Increase in waterproofed area
			Energy production	Anthropogenic heat

Our work consisted in combining this regulatory approach of urban form with a climatic approach developed in the scientific literature. The causes of Urban Heat Island, on which it is possible to act and

urban parameters which influence them, are clearly identified [6]. The definition of the various articles of urban planning regulations allows to identify regulatory urban parameters. The relationship between urban planning regulations and the causes of Urban Heat Island is summarized in Table 1.

3. Simulators operation

A coupled model that allows to qualify and quantify all the phenomena to be studied (urban growth of the territory and changes in urban planning rules, Urban Heat Island and climate change) is at the centre of this work.

In particular, it involves using existing digital models to script urban development, visualize the urban form in 3D and analyze their impact on the microclimatic behavior of cities.

3.1. SLEUTH model for urban growth

SLEUTH (Figure 1) is a cellular automaton model created in 1996 [7] which simulates the expansion of the future urban patch of a territory by providing regional forecasts of the urban extent in 2D. It has been used many times in research studying the impact of urban growth on urban energy [8, 9]. It was modified towards a scenario-oriented operation Foresight [10] in order to be able to simulate urban growth from the qualitative scenarios (narrative).

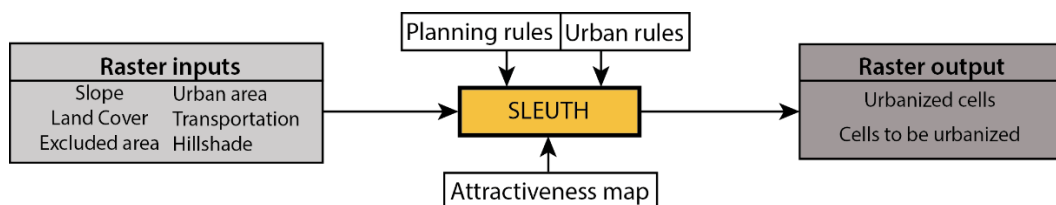


Figure 1. Descriptive diagram of the operation of SLEUTH model

SLEUTH can simulate several types of growth (spontaneous, diffuse, organic, influences by the road network), characterized by five parameters (diffusion, multiplication, propagation, slope and gravity of the road). The model input variables (Slope, Land Cover, Excluded, Urban Transportation and Hillshade) are readily available or generated.

3.2. SimPLU model for 3D constructability

For many years, models simulating built forms, constrained by local regulations resulting from urban planning policies, have been developed.

In France, the SimPLU model (Figure 2) was developed within the LASTIG laboratory [11] to model the constructability of a plot in 3D, taking into account the urban planning regulations that apply to it. It is a generator of built forms adapted to the regulatory constraints of the French terrain. It automatically generates different built forms taking into account the point of view of a “builder agent” and visualizes the results in 3D within an existing urban area.

Different development scenarios are simulated using parameters of shapes and objectives (which simulates different configurations and decisions of agents).

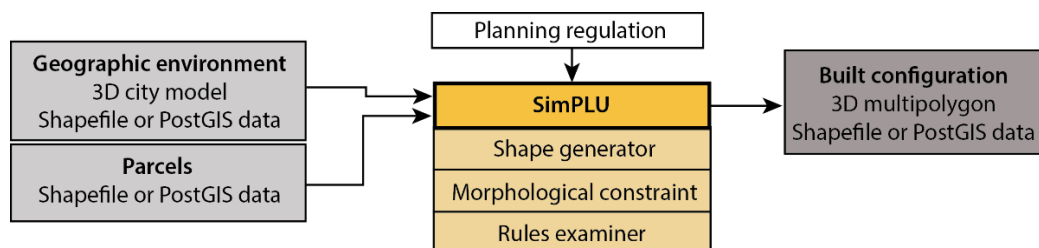


Figure 2. Descriptive diagram of the operation of SimPLU model

Recently, it has been used in a work coupling it with another model. Colomb [12] coupled existing models with the objective of simulating different residential configurations by selecting buildings plots from MUP-City, which is an urban growth model [13], and by modelling the construction potential in 3D of each location.

3.3. SOLENE-microclimat for microclimatic simulation

SOLENE – microclimat (Figure 3) is a tool dedicated to the simulation of urban microclimate. It consists of an integration of several models: thermo-radiative model, a CFD model and a thermal building model [14].

It has been developed since the 1990s by the CRENAU laboratory. It is constantly improving to take into account a set of phenomena such as radiation transfers, the effects of radiation on urban surfaces, wind distribution, evapotranspiration, natural elements (vegetation and water surfaces) and the energy balance in the case of the simulation of an area.

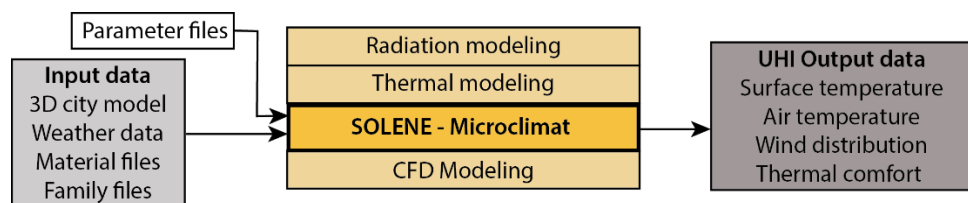


Figure 3. Descriptive diagram of the operation of SOLENE - microclimat model

It simulates different urban development configurations at the district scale on climatic indicators such as air and surface temperatures, outdoor and indoor comfort, energy consumption of buildings, etc. [15]. This model has been used in numerous studies aimed at attenuating the Urban Heat Island by simulating the influence of vegetation in the city [16], the choice of construction materials [17], the evolution of the urban form [18], etc.

3.4. Models coupling

This coupling (Figure 4) aims to determine whether Urban Heat Islands can be mitigated through action levers within Local Urban Plans. It aims to understand what urban rules could anticipate UHI.

The approach to this work is scenario-oriented to allow the integration of scenarios as they are developed within Local Urban Plans. We have chosen to develop contrasting and plausible urban development scenarios taking into account a set of parameters such as the shape of the urban fabric (urban, vegetation, infrastructure), energy and digital management of the territory combined with climate change scenarios defined by the IPCC [19]. Scenarios are quantified with a view to their integration into the different models used.

The SLEUTH model is configured to simulate the urbanization of the territory up to 2100. The choice of the type of growth will be defined according to the scenario, while prioritizing an urbanization in continuity with existing urban area and close to infrastructures to simulate cells to be urbanized.

Thanks to a parcel divider, from urbanized cells, we obtain, after definition of the division rules, plots to be urbanized.

From these plots, the SimPLU model simulates 3D built configurations according to the regulatory constraints that apply to them according to urban zoning. When all the plots to be urbanized are built and modelled, a 3D urban form is obtained.

The last step consists in simulating the climatic behaviour of this urban form within the SOLENE – microclimat model, thanks to the weather data of the study region, we carry out step-by-step simulations and principal component analysis of different urban scenarios to determine:

- The impact of various urban parameters resulting from urban planning regulations on Urban Heat Island.

- The impact of various global scenarios on the mitigation of Urban Heat Island and climate change.

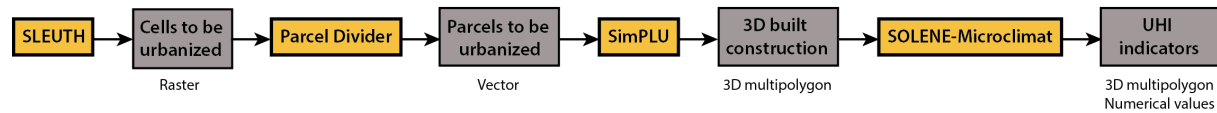


Figure 4. Descriptive diagram of coupling of SLEUTH, SimPLU and SOLENE - microclimat

4. Development prospects

This first example of the coupling (Figure 5) of SLEUTH, SimPLU and SOLENE – microclimat models is being developed as part of a PhD thesis, in order to simulate the territorial development and the constructability in accordance with urban regulations of the Local Urban Plan and urban microclimate.

All the models used have already been the subject of numerous studies [8-11, 14, 16-18], which have validated their ability to reliably and realistically reproduce the complex phenomena that we are studying and to make their use relevant in the context of a coupling.

The objective of this tool is to assist the urban stakeholders who lack tools of anticipation of the impact of their decision on Urban Heat Island development. This coupling combines planning orientations taken by urban decision-makers with climate sciences while taking into account the specific changes in our societies. More specifically, the tool qualifies the urban form based on regulatory approach, which takes into account specific languages used in urban planning policies. Its development helps decision making by making the choices more informed and interpretable, and helps to optimize urban planning policies and thus anticipate Urban Heat Island development.

It models different urban development scenarios and assess their impact on urban microclimate. To illustrate the functioning of the coupling and how it can in practice model urban planning policies and their impact on Urban Heat Island, we are carrying out a study. Based on the use of planning regulations of the Local Urban Plans and weather data it will take place in Montpellier Méditerranée Métropole.

Future works aim to extend the assessment of the impact of urban planning on Urban Heat Islands by implementing the coupling. New components such as the establishment of a regulatory climate classification, based on similar approaches [20] will be added simplify the understanding of the results by urban planning decision-makers.

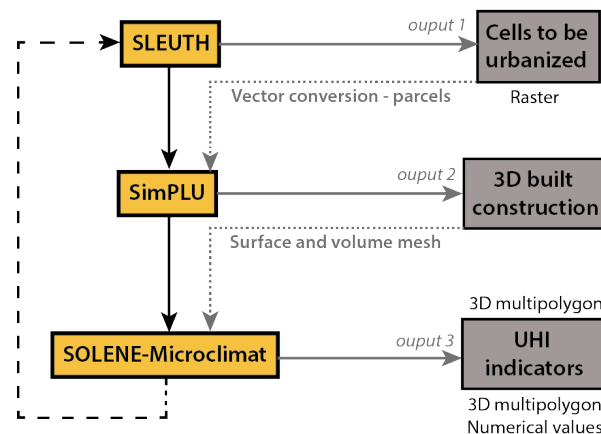


Figure 5. System defined from several simulators

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