Simulation of urban blocks densification

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ABSTRACT

This paper addresses urban block densification in a simulation context. The simulation of such a process requires several spatial analysis tools and specific knowledge on the types of objects accounting for the increased urban density. In this paper, only buildings creation is considered. The method proposed hereby takes into account the existing spatial organisation of an urban block in order to respect it while creating new buildings.

1. INTRODUCTION

The GeOpenSim research project aims at developing an open source framework to study the evolutions of urban spaces. This project regroups 4 French laboratories (LSIIT, LIVE, CEDETE and COGIT). Studying urban dynamics requires to hold spatio-temporal databases or to be able to build them using existing data. It also demands to be able to track the evolutions of the observed objects in their consecutive states (Perret, 2009). This step is decisive in building evolution patterns by analysis. Finally, these evolution patterns (or rules) can be used to simulate urban dynamics with a multi-agent system. The main goal of such simulations is to validate identified knowledge on observed urban dynamics. This paper does not address the construction of spatio-temporal data or the identification of evolution rules, but focuses on the spatial organisation produced during urban dynamics simulation and on a method to control it. More precisely, it deals with a specific type of urban evolution - densification - and a specific geographic level - the urban block.

Existing approaches to urban simulation mostly use cellular automata (Badariotti, 2007, Barros, 2003, Batty, 2005, Benenson, 1997, Couclelis, 1997, Lajoie, 2007, Schürmann, 2002, Werner, 2009) or graph cellular automata (O'Sullivan, 2001). (Hammam, 2007) presents a geographical vector agent model, but it does not apply to urban dynamics. Our simulation approach, vector-based, relies on a multi-agent system where each agent is a topographic object. All topographic objects are agents, including meso-geographic objects such as urban blocks, districts and cities, thus forming a hierarchy of agents interacting inside an open system.

The behaviour of agents is first influenced by the evolution rules (or patterns) used for the simulation. These rules can either be identified using spatio-temporal analysis and machine learning or determined by experts. The role of these rules is to set goals for the agents. Usually, these goals present themselves as objective measures: for instance, such a measure can be a given urban block density that the urban block is supposed to reach at the end of the simulation (cf. Figure 1).
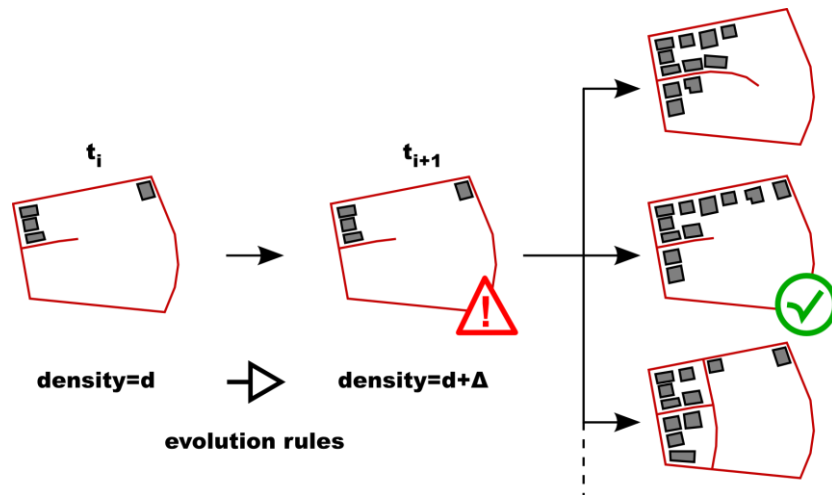
Figure 1: Evolution rules set an objective density value to the urban block. After the application of the evolution rules, the agent has to choose between different actions in order to satisfy its constraints. It chooses the action that produces the best constraint satisfaction.

Each agent holds a set of constraints regulating its behaviour. Indeed, at each activation, an agent evaluates its satisfaction by weighting the satisfaction of its constraints. Each unsatisfied constraint suggests a list of actions that, if applied, should benefit the agent.'s satisfaction After careful consideration, each agent chooses its best course of action and goes through with it. If its satisfaction is not improved after the application of its actions, the agent can backtrack to its previous state and choose another course of action, thus creation a tree of potential states (cf. Figure 1).

Finally, agents use populating functions to create new agents. These functions allow each agent responsible for the creation of new agents to choose the appropriate strategy to do so. For instance, urban blocks, when creating new buildings, can choose to respect their existing spatial organisation or to radically change it.

GeOpenSim's framework depends on GeOxygene, an open source GIS initially developed at the COGIT laboratory. It is organised in modules, each tackling a specific problem: spatio-temporal databases construction, spatial analysis and data enrichment, simulation, evolution rules construction, state evaluation. The next section presents the populating functions. The different types of densification are introduced in section 3. Finally, algorithms responsible for buildings creation and location are presented in section 4.

2. EVOLUTION RULES AND POPULATING FUNCTIONS

The simulation of urban densification requires the use of evolution rules such as: *X% of geographical space with such geometrical and geographical properties might evolve in such a way during this time period.* As mentioned in section 1, these general rules can be deduced from analysis and comparison of existing topographic data at different dates or determined by experts. In addition to these evolution rules, the simulation module requires other rules, more specific and local, to add new buildings or new roads within urban blocks, while respecting their spatial organisation. These specific characteristics allowing to guide the creation of new objects in a geographic space are gathered in the populating functions.

This section focuses mainly on buildings creation. The most relevant properties used in the creation and location of new buildings in an urban block are the following:

- The **name of the populating method**: this name characterizes the type of urban block or city district and gives a first indication of the kind of buildings erected in this area. For instance, a *housing project* describes an area where tower blocks and apartment buildings will be dominant. The type of urban block is achieved by a supervised classification using expert knowledge (Lesbegueries, 2009).

- The **time period**: this is the period during which the populating method can be applied. Indeed, some types of urban areas, both by spatial organization and buildings shape, are specific to a period of time. The time period model we use is a simplification of the TimeOrdinalEra defined in (OGC, 2007).

- The **building's nature/function**: Three different functions are considered: public, industrial and residential. When lacking additional information, the building's function can be used to choose its shape (because the latter is most often related to the former).

- The **building's characteristics**: A building is characterized by its area, its shape and its probability of occurrence. The shape refers to a specific shape in a library containing common building shapes (square, rectangle, U-shaped, L-shaped, T-shaped, etc.). The probability of occurrence gives the probability for a building of this nature to have this shape. A populating function can contain several types of building characteristics. For example, a *housing project* may be composed of large squared tower blocks and huge rectangular low-rise apartment buildings.

- The **distance to the road**: This measure is related to the concept of accessibility and is particularly important for some buildings such as the houses in residential areas. In an urban block, new buildings' distances to the road respect a normal distribution with the given standard deviation and mean value.

- The **distance between a building and its neighbours**: This distance significantly differs according to the urban block type. For instance, the distance between a building and its neighbours is more important in housing projects than in residential areas but it can also differ in residential areas according to the standard of living. In an urban block, new buildings' distances to the neighbouring buildings respect a normal distribution with the given standard deviation and mean value.

- The relative **orientation of the building to the road**: This parameter specifies whether the building is lined up along the nearest road (or river) or not.
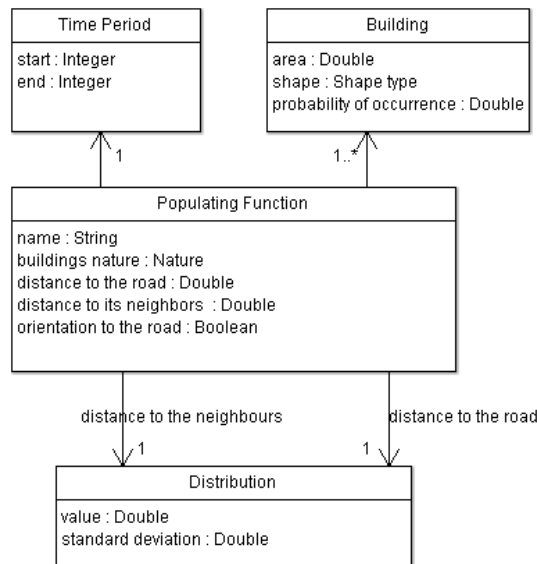

Figure 2: UML diagram of the populating function

3. DENSIFICATION TYPE

The densification of an urban block consists in adding new buildings according to the rules defined in the populating method. These rules must allow generating many different kinds of urban spaces from residential to industrial areas. Table 1 gives some examples of populating methods using the properties described in 2. The purpose of the examples given here is not to define realistic parameters that can be applied to populating methods, but rather to illustrate the wide variety of urban spaces which can be obtained using the proposed method. Note that for a given populating method, the standard deviation parameters on distance values allows to control the regularity of the produced organisation, thus allowing for a certain variety when using high standard deviation values.

Name	Nature	Buildings characteristics	Distance to the road	Distance to the other buildings	Parallel to the road
Working class Houses	Residential	Square or rectangle with a very small area	Small distance	Small distance	True
Middle class Houses	Residential	More varied shape with larger area than working class houses			True
Upper class Houses	Residential	More varied shape with larger area than middle class houses	to	to	False
Apartment buildings	Residential	Large square			True
		huge rectangle			
Industrial zone	Industrial	Large square	Large distance	Large distance	True
		huge rectangle			

Table 1: Examples of different populating methods.

The appearances of urban blocks after densification by 3 distinct populating methods for residential housing are very different (Figure 3 b, c and d). The result for the "working class housing" method shows a particularly homogeneous and compact organisation with small houses on small lots. An increase in standard of living comes with different housing forms and increased lots' size. The result for the "upper class housing" method is a low density urban block, supporting a few private houses with heterogeneous shapes. The two other populating methods applied in the same urban block, which create respectively an apartment buildings area and an industrial area (Figure 3 e and f), differ mainly by building size and distance between the buildings. The examples given here only illustrate the method and many other populating functions can be defined. Further research on this subject will involve expert knowledge and machine learning in order to define more accurate parameters.
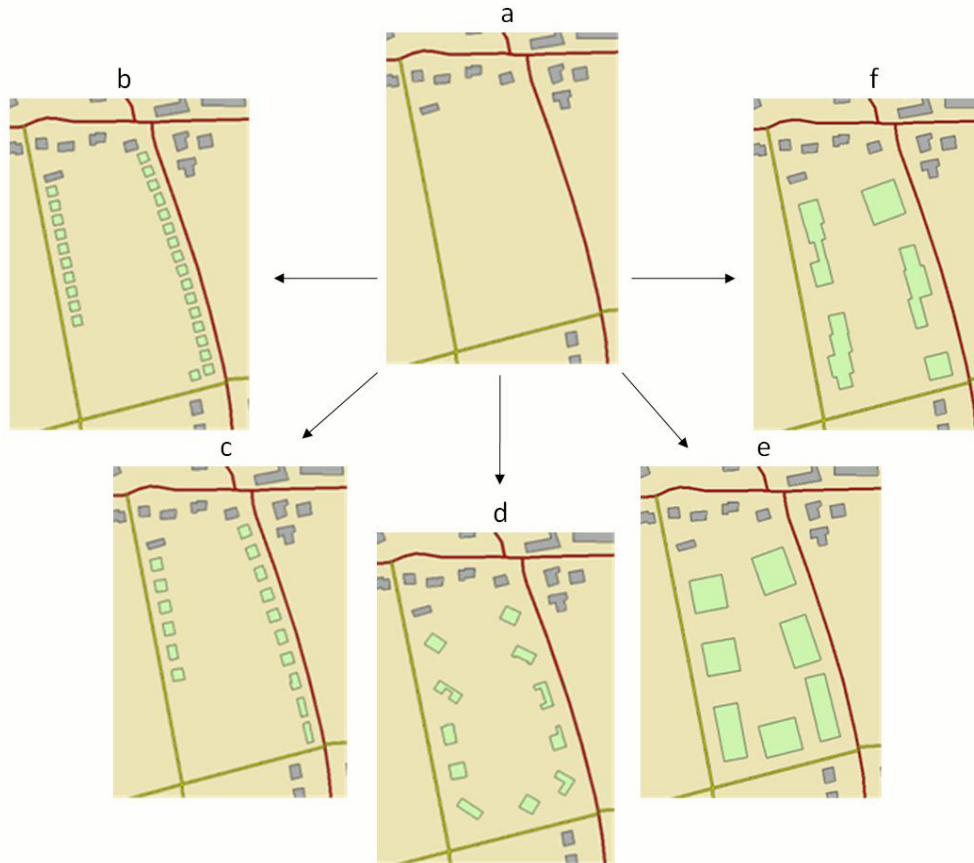
Figure 3: Simulation results illustrating different types of densification from the same initial urban zone (a): densification by "working class houses" method (b), densification by "middle class houses" method (c), densification by "upper class houses" method (d), densification by "industrial zone" method (e) and by "apartment buildings" method (f).

4. CREATION AND LOCATION OF NEW BUILDINGS

The creation of a new building within an urban block requires two steps: 1- to create a new building and 2- to place it in the best possible location. These two steps don't necessarily come in this order. In this paper, two additional methods have been developed.

For the first method, the two steps described above are almost independent of each other. A new building is created from the characteristics of the chosen populating method and, at the same time, the best constructible area is determined from the properties of the populating method and urban block characteristics (Figure 4). This area corresponds to the area located: 1 - in proximity to the road, in order to respect the accessibility constraint, 2 – not too close to the road and to the other buildings in accordance with the properties defined in the populating method. The new building is then placed within the largest part of the constructible area. The density of neighbouring urban blocks may also be

considered to position the new building. When the best position is determined, the building must adapt to the available space and modify its new geometry by moving, rotating, and resizing it.

The main limitation of this first method relates to the independence of the two steps. If the new building does not fit in the initial space, the building's adaptation to the available space may take a long time and above all may drastically change the initial (and wanted) characteristics of the building.
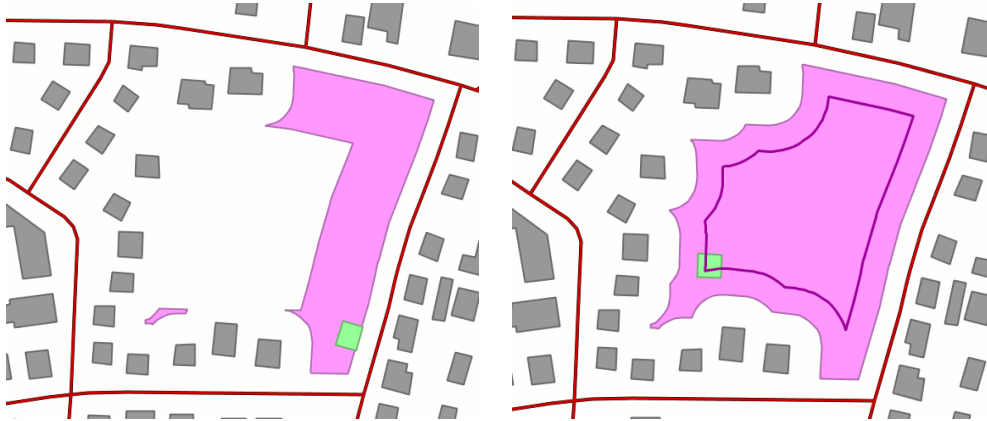

Figure 4: Constructible area (in pink) and a new building (in green) for the first method (left) and the constructible area (in pink), the medial axis (in violet) and a new building (in green) for the second method (right).

For the second method, the steps described above are in reverse order. The building is created only when its location is established. First, the "maximal space" required for the new building is determined from the building properties (area and elongation) stored in the populating method. The second step consists in searching, in the urban block, the empty spaces of sufficient size to contain the "maximal space" determined previously. The algorithm used, here, to define these spaces of sufficient size is based on the computation of the medial axis of the constructible area (Figure 4). The new building is then created at this location (along this axis) from the properties of the populating method.

This second method is better adapted to the positioning of huge buildings than the first method because it doesn't modify the initial characteristics of buildings. The first method, contrary, gives good results for the positioning of small buildings along the road. The choice of the method used to create and locate a new building will then depend on the building size.

Whatever the strategy used to add a building to an urban block, building's characteristics may be obtained either from populating method, or from mimicking its neighbours. The imitation process can be used to continue the same densification type of an urban block. For example, if the goal type is "working class houses" and there are already many little square houses in this urban block, a strategy of mimicking may be applied. In this case, the main properties controlling characteristics and location of a new building may be deduced from the analysis of the urban block or its neighbours. On the contrary, the populating methods are used to compensate for a lack of knowledge or to change the densification type of an urban zone. This is, for example, the case when the goal type is "working class houses" but there is no building in the urban block.

Different behaviours can be used to adapt the geographical position of a new building to the constraints linked to its environment. These behaviours are mainly: 1 - displacement behaviour to

enhance the constraints linked to the distance to the road or to the other buildings and 2 - the rotation behaviour to line up the building along the nearest road. The displacement behaviour is based on previous work on building generalisation (Ruas, 1999). The proximity between the building and the other objects (its neighbours and the road) is computed from constrained Delaunay triangulation. The displacement is then characterized to optimise the constraints of distance to the road and to the other buildings. Finally, other behaviours can be defined using other meso objects: the buildings can be constrained to resemble the other buildings in the same building group or to align to the other buildings in a close alignment (Christophe, 2002).

5. CONCLUSION AND PERSPECTIVES

In this paper, a method for the simulation of urban densification at the urban block level has been presented. The proposed simulation process takes place within a larger framework for the analysis and the simulation of urban dynamics. The development of this framework is the goal of the GeOpenSim project. This project, funded by the French Research Agency (ANR), is a collaboration between four French research laboratories led by the COGIT laboratory.

The main contribution of this paper concerns the proposal of a method and associated algorithms aiming at populating urban blocks with new buildings according to a specified spatial organisation. The main limitation of this approach is not to take into account parcel data, and thus simplifying the actual existing spatial organisation (constrained by parcel data, land use, etc.). Nevertheless, this limitation is a choice: the goal of the project being to be able to analyse and simulate urban dynamics, even with few data. Future work will address this issue by allowing the use of parcel data when available. This will also be useful in order to evaluate more thoroughly the results of the approach presented here. Another perspective concerns the integration of roads and service roads to populating functions. Indeed, different types of densification call for different types of networks.

In this paper, we focused on how to add new buildings to urban blocks using a given strategy. In the broader GeOpenSim context, this process is triggered only once evolution rules have been applied, i.e. only after the target density and the populating method have been chosen. The construction of the evolution rules is an ongoing task for the project and the very rich literature on the subject provides us with a wide choice of parameters to study. In particular, future work will involve taking into account land use change, building heights and public policy.

Other interesting perspectives involve the possibility to integrate urban economics (Gusdorf, 2008), social simulation (Holm, 2002, Insee, 1999) and to integrate the simulated city into a system of cities (Bretagnolle, 2009).

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