Stochastic buildings generation to assist in the design of Right to Build plans

Mickaël Brasebin, Julien Perret, Romain Reuillon

Abstract The design of documents impacting potential new constructions, such as Right to Build plans, is a complex issue. New tools need to be proposed in order to systematically assess the impact of regulations on the building potential of the concerned areas. Furthermore, it is often not directly the morphology of new constructions that administrations and citizens would like to regulate but their properties with regard to other phenomena (solar energy potential, etc.). In order to tackle these issues, we propose in this article to explore building configurations and regulations using a stochastic building generator and a workflow engine. The workflow we propose for such an exploration will produce important amounts of data that we intend to release as OpenData in order for administrations, urban planners and citizens to be able to freely visualize and collectively choose the regulations that best suit their territory. Such amount of 3D geographical data also suggests new issues in geovisualization.

1 Introduction

The development of cities is usually regulated by a set of plans designed by local administrations that concerns different objects (i.e. construction, environment, transportation). These plans offer administrations a control over city evolutions supported

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by non public actors (for example, citizens, and promoters). Generally, the scope of such plans is determined by national laws that define which objects are concerned by a given regulation and which types of regulation can be applied on these objects. However, their designing phase is a difficult task. [Papamichael and Protzen, 1993] defines it *"as an activity aimed at producing a plan which is expected to lead to a situation with specific intended properties and without side- or after effects"*. Thus, a good plan design requires a systematic assessment on a whole territory. As the knowledge of such plans is expressed though textual legal texts, a very first steps is to offer the possibility to correctly traduce such knowledge into a simulation system. Furthermore, as it regulates the behavior of various city actors, such a system has to integrate their different strategies notably to detect possible loopholes in regulations in order to avoid unwished developments. Another issue is that the designer may want to control some phenomenon linked to objects regulation but without possibility to directly limit them.

For this work, a particular plan is considered: the Right to Build. Such a plan aims to control new constructions by defining a set of functional and morphological constraints. The interest of this plan is that it limits the development of the urban fabric which is strongly linked with environmental phenomenon (such as photovoltaic electricity production or urban heat island effect) that designer tends to control. However, regulations do not allow to directly control them. For example, in French regulation, the French National Urban Code allows the limitation of 3D shapes (i.e. height, roof slopes) in Local Right to Build Plans but forbids fixing a minimal solar energy received by building facades.

As the design of such plans is a progressive process that may introduce new problematics during discussions with actors; it requires testing new properties. Thus, our proposition is based on a database of possible building configurations (based on city actors behaviors) on which the designer can test these evolutive properties. The idea of testing the properties on a database is to separate actors behaviors from designer expected properties and to limit time calculation as the production of new databases is time consuming on a whole territory. The designer may test a large variety of properties without assessing new databases.

The aim of this paper is to propose a system that assists the design of plans by the exploration of potential configurations allowed by possible regulations. The idea is to inverse the design of regulation and to determine it according to a set of expected properties. Firstly, we present in this paper a review of works related to building generation and aided design about Right to Build assesment (section 2). In our work, we consider two levels:

- A first level is the production of a possible building configurations database that represents Right to Build according to actors behavior and according to scenarios of regulations (section 3);
- A second level is the determination of regulation scenarios that match with designers expected properties. We also discuss about possible uses and explorations of generated configurations (section 4).

2 Related work

In order to produce building configurations, our system needs a building generator that integrates Right to Build regulation.

Building generation: Building generation is a technique used in several domains including architecture, geosimulation, computer graphics and urban planning. Thus, numerous systems are designed with specificities according to its domain. Vanegas distinguishes two types of generators, not totally incompatible: geometric simulator (for example [Parish and Müller, 2001, Müller et al., 2006]) and behavior based simulator. Only the second one takes into account or imitates human processes that produce buildings. This kind of simulator is widely used in territorial studies and traduces human behaviors through utility functions. Thus, optimization methods are generally used for this kind of simulators to optimize the utility function: Multi-Agent Systems [Ruas et al., 2011] or meta-heuristics like evolutionary algorithms [Frazer, 1995] or simulated annealing [Bao et al., 2013] combined with geometric generative methods like primitive instancing [Perret et al., 2010, Kämpf et al., 2010] or shape grammars [Talton et al., 2011].

Generation with urban regulation: Among these generators, a set of propositions is focused on the integration of Right to Build regulation in order to assess constructability. It is assessed by producing buildable hulls from geometric constraints [El Makchouni, 1987, Murata, 2004, Brasebin et al., 2011]; offering the possibility to explore a predefined set of parametric buildings respecting rules [Coors et al., 2009]; generating buildings [Turkienicz et al., 2008, Brasebin, 2014] or proposing extensions to existing buildings [Laurini and Vico, 1999].

Design with building generation tools: As it is possible to generate rapidly lots of buildings with such tools, methods have been designed to support decision making with building generation. For example, [Kämpf et al., 2010] propose a multi-objective genetic algorithm that tries to determine the height and the roof shape from a set of building footprints in order to optimize both built volume and solar energy received by building surface. The designer can explore the Pareto front in order to choose a solution that provides the best compromise. [Vanegas, 2013] proposes to determine parameters from building grammar generation tool in order to reach environmental objectives (natural light, built density or visibility to landmark). In [Talton et al., 2011], an original solution is described to design the skyline. These authors provide a method that generates buildings according to a grammar in order to match with an objective shape seen from a view point.

If these methods are interesting to support decisions; they give one solution for an optimal set of properties and do not investigate the varieties of optimal configurations. Studying this variety is important as city actors do not always act rationally (i.e in our problem produce optimal configuration) and may create sub-optimal solution that can cause undesirable effects. In this paper, we try to propose a solution that allows studying these sub-optimal configurations.

3 Proposition

Our proposed system is described in figure 1. The main idea of this system is to explore on a studied geographic zone (section 3.1) a space of possible regulations (section 3.2) for which adapted building configurations according to its input parametrization are generated (section 3.3). In order to guide the propositions, a utility function determines which solution are good enough to be kept and some variety criterions are introduced in order to keep solutions variety (section 3.4). The sampler proposes configurations to the classifier during a certain duration, these solutions are kept according to their variety criterions and the utility function value (section 3.5). The processing of this exploration (section 3.6) tool produces as final result a database that includes building configurations that optimize a utility function according to variety criterions.

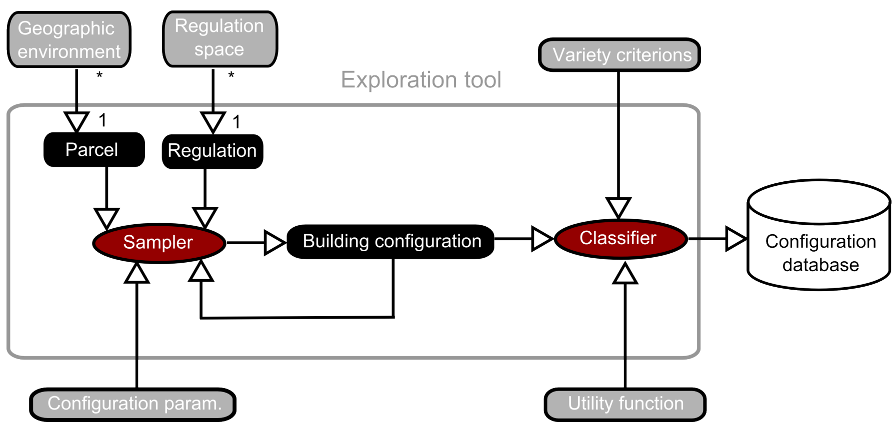


Fig. 1: Global schema of our proposition to produce a database of building configuration according to a regulation exploration space.

3.1 Geographic environment

The geographic environment delimits the studied zone. It contains a set of objects described in a model that extends existing standards (CityGML [Gröger and Plümer, 2012], COVADIS [Covadis, 2012], INSPIRE [INSPIRE, 2009]). The full model is presented in [Brasebin, 2014] and can be summarized in figure 2. The geographic environment contains notably a set of parcels on which the sampler can independently generate building configurations. The model also integrates existing buildings at different levels of detail (LOD1 or LOD2) that can influence constructability due to regulation (i.e distance between buildings, maximal floor area ratio, etc.). The different integrated objects, their properties and their relationships can be used to define regulation that can be applied on sampled configurations.

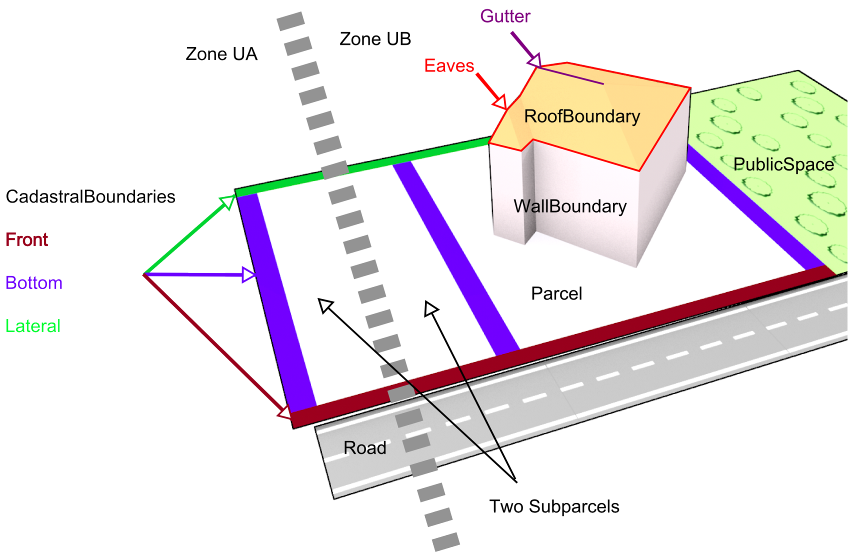


Fig. 2: Geographic environment to support rules definition.

3.2 *Regulation space exploration*

In order to test different regulation scenarios, the designer has to define the space of possible regulations $\mathfrak{R}$. Thus, we consider a regulation as composed of a set of constraints: $r = \{c_i\}$ with $\{0 \leq i \leq n\}$. This single regulation is a parameter of the sampler in order to constraint generated building configurations. Each *const* is a Boolean function with parameters that indicate if a configuration c respects the constraint: $const(p,e,c,\{param_i\}) \in \mathbb{B}$ with $\{param_i\} \in \mathbb{R}^n$. For each $param_i$ an exploration space is defined. For example, in Right to Build regulation, a constraint can be a building height limitation, the parameter is the height value and the search space a set of values $\{10$ m, 15 m$\}$. Furthermore, the designer may test different constraint alternatives for a rule. Thus, for each $const_i$, the designer can define a set of $const_{i,j_i}$ that can be alternatively effective to form a regulation. With this notation, we can write that $\mathfrak{R} = \{const_{i,j_i}(p,e,c,\{param_{i,j_i}\})\}$. Then, the exploration task consists in simulating each $r \in \mathfrak{R}$. c is a building configuration as defined in the next section.

3.3 Building configuration sampler

In order to sample, we use a RJMCMC (Reversible-Jump Markov Chain Monte Carlo) sampler as described in [He et al., 2014, Brasebin, 2014]. Indeed, a RJMCMC sampler allows us to simulate building configurations of varying dimensions [Green, 1995] (we do not have to set the number of buildings in advance for instance). It takes in inputs a parcel p in a geographic environment e and a regulation r formed by a set of rules. This sampler allows the generation of building configuration formed by a set of n objects. n is automatically determined by the system. In our experiments, used objects are boxes b described by a set of parameters $b = (x, y, l, w, h, \theta) \in \mathbb{R}^6$: position of its center (x,y), length (l), width (w) and orientation (θ)[1]. Parameterization of the sampler concerns the space sampling of the boxes, notably the minimum and maximum dimensions (width, height, depth) of boxes. Thus, we introduce a sampling function as: $sampling(p, r, e) = c \in (\mathbb{R}^6)^n$

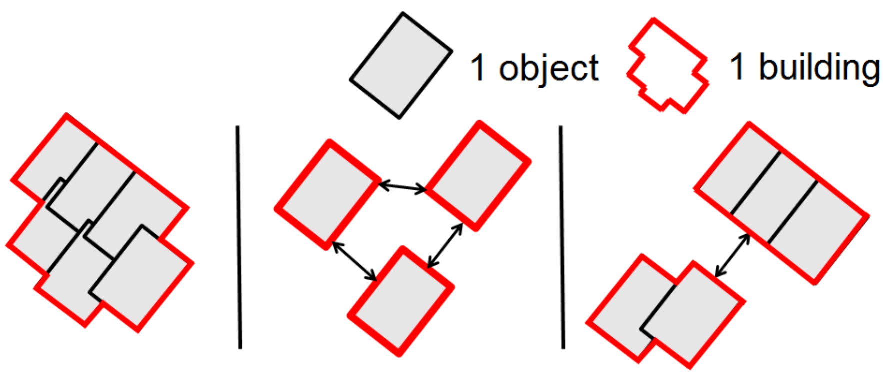


Fig. 3: The different types of building configuration.

Furthermore, the sampler offers the possibility to generate different categories of building configurations (represented in figure 3), it can be composed by:

- n configuration of 1 box, for example to simulate individual buildings;
- 1 configuration of n boxes, for more complex buildings;
- or a mix of other types m configuration of n boxes.

The interest of this sampler is that generated configurations are relatively free and does not require initial knowledge as they are only composed of boxes. This allows the proposition of greater variety of configurations than in systems based on

[1] But other parametric objects can be used instead.

predefined construction processes. Nevertheless, unlikely combinations of building footprints might be generated. In this case, one can avoid such configurations by changing the parameter space (the dimensions of building footprints for instance) or by adding ad hoc constraints of the configurations.

3.4 Utility function

The utility functions $\mu(c,e) \in \mathbb{R}^n$ aims to define the effectiveness of a configuration and to compare it to other ones in order to determine which one to keep [Michalewicz, 1994]. Thus, c is better than c' if $\mu(c,e) > \mu(c',e)$. This function has to embed the characteristics of the ideal solution and is the only link to control proposed configurations. In the context of building generation, the utility function can traduce an expected builder strategy (i.e. volume optimization in order to benefit from Right to Build). It can also be used to produce configurations that incite undesirable behaviors in order to detect possible loopholes in a tested regulation (i.e. maximization of shadow projection on neighbor parcels in housing estates).

3.5 Building configuration classifier and solutions variety

In order to explore the variety of configurations proposed by the sampler, we propose to use a method to calibrate multi-dimensional models [Reuillon et al., 2015]. The global idea of the method is to define a n-dimensional function $h(c,e) \in \mathbb{R}^n$ with $\{h_i(c,e)\}_{0 \leq I \leq n}$ that assesses configuration diversity. For instance, in our problem h_i can represent the number of boxes in a configuration the built ratio on considered parcel or other morphological indicators. Thus, it is possible to classify a configuration in a $\mathbb{R}^n$ dimension space. For this classification task, each dimension is discretized according to possible h_i value ranges. In the case of continuous morphological indicators, the appropriate number of buckets has to be determined on an individual basis. During the processing of the exploration tool, an evaluation of $h(c,e)$ is processed and the configuration is classified in a n-dimension cell according to $\{h_i(c,e)\}_{0 \leq I \leq n}$ value. For each cell a configuration is stored and replaced by better configuration (in terms of utility function μ) when met. Figure 4 illustrates the process in a 2-dimension space.

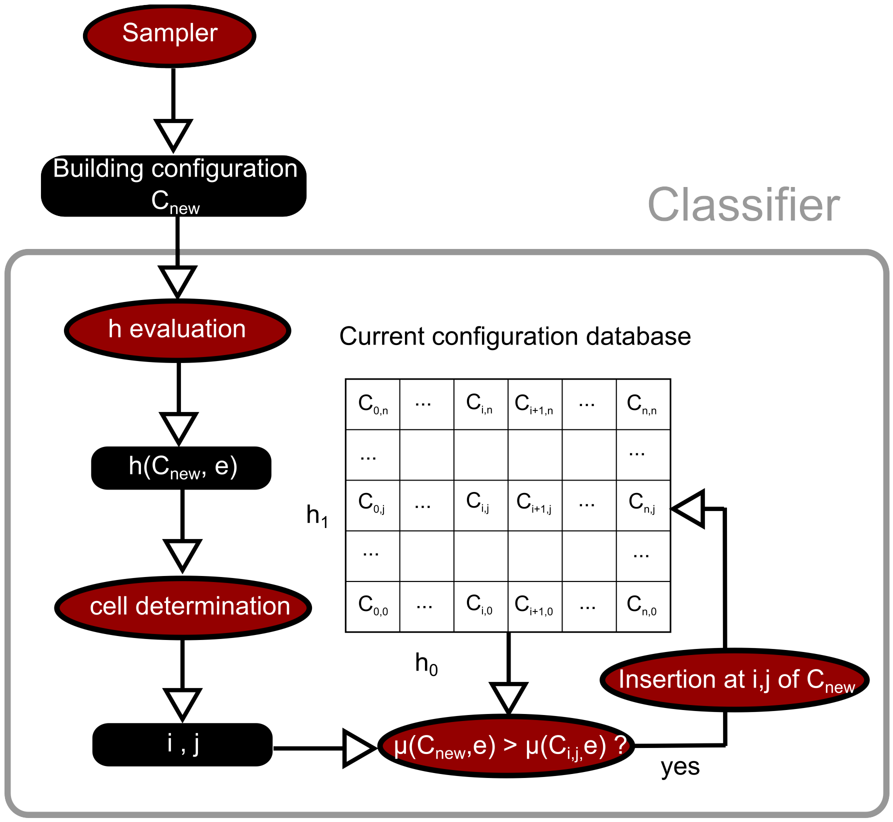


Fig. 4: Classification steps applied on a configuration with a 2 dimension variety function.

3.6 *Execution of the exploration tool*

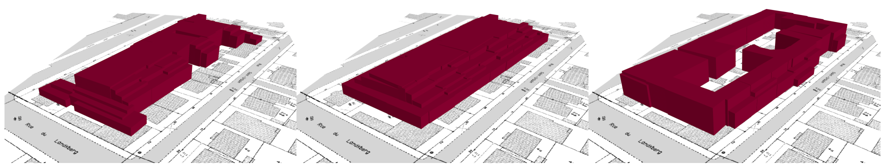
As the exploration tool is ran for one regulation and one parcel[2], it is possible to distribute the execution of the whole system. Thus, for each pair $(r \in \Re, p)$ a partial configuration database $d_{r,p}$ can be produced. The production of such database can be modeled as an optimization process whose aim is to optimize the sum of all utility functions $\sum_{c \in d_{r,p}} \mu(c,e)$ and we propose to solve it with a simulated annealing algorithm. End condition is reached when there is no improvement during a sufficient number of iterations. It depends on the size of the search space. Methods to efficiently configure the optimization function are provided in [Salamon et al., 2002]. The final database d is the union of all partial databases.

[2] Or a urban block if simulations take into account new buildings from neighbor parcels

4 Uses of generated configurations and exploration

In the previous section, we present a method to generate possible building configurations in order to produce a database. We discuss here the different possibilities to exploit such database.

4.1 Direct extraction of building configurations



(a) (b) (c)

Fig. 5: Several generated building configurations on same parcels: with prospect constraint and 0.5 as maximal built ratio (a) ; with prospect constraint (b) and minimal distance to road and with distance to bottom seperative limits and to road (c).

A very first result is the possibility to extract configurations for a set of parcels (some examples are presented in figure 5). At first intuition, we consider two approaches to extract such information:

- **Naive query**: a configuration per parcel is extracted according to a relevant partial database;
- **Best configuration query**: in order to get best configuration, this method extracts from each partial database configuration with the best utility function.

If these solutions are useful to help the designer in choosing scenarios of interest, they do not take into account the variety of generated configurations. Indeed, exploring a significant number of configurations can be quite time consuming.

4.2 Inverse design

The aim of inverse design is to determine relevant objects from a set of properties. In the context of Right to Build regulation, the idea is to find the right regulations in order to preserve or optimize this set of properties (figure 6). As regulation design concerns various actors with different domains of interest (i.e. solar energy development, public park preservation, etc.), several sets of properties have to be tested in order to find a compromise between these different issues. For each issue, the corresponding set of properties is optimized in order to find in the database the best candidates in terms of properties optimization but also in term of diversity. Thus, we suggest preserving non-optimized solutions to enrich discussions between actors and to reinject them in order to explore some new aspects to assess if they fulfill requirements for being good compromises. As the exploration task described above may be time consuming, it seems to be relevant to reuse the configuration database to explore these city aspects not taken into account through utility function.

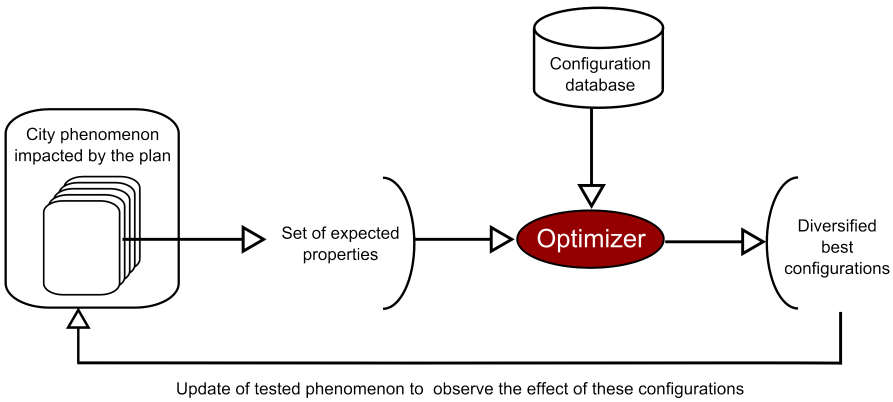


Fig. 6: Use of building configurations database to support inverse design.

4.3 Navigation between configurations from the inverse problem

In order to take into account the variety of configurations that provide good results for a given inverse problem, we will explore in a next step the different possibilities to visually analyze building configurations.

Two types of works retained our attention:

- **Interpolation between configuration**: [Bao et al., 2013] propose a method to produce intermediate building layout between two generated configurations. This method may be interesting if we want to interpolate building configurations between two regulations or between two variety measures. The major interest is to allow a smoother navigation in order to simplify the user observation and maybe to find a compromise between two solutions.
- **Navigation between configurations**: As inverse design generates different configurations, the idea is to provide a visualization of neighbour configurations according variety function evaluation (some operational propositions can be found in [Averkiou et al., 2014, Kleiman et al., 2013]). For one parcel or urban block

of interest, it offers the possibility to see different configurations that solve similar problems but with different morphological aspects assessed by the variety function.

5 Conclusion

We present a proposition to simplify the design of Right to Build regulation with the exploration of building configurations. The main idea is based on the production of a building configurations database that integrates solution variety. Thus, the designer can explore different aspects of these building configurations in order to rapidly test different sets of properties that represent phenomena from considered territory. A research agenda is proposed in order to query this database and to interact with its content.

In the future, we will produce such a database on a zone of interest by using two open projects:

- **Open-Mole project** [3] to parallelize the different tasks of the exploration process;
- **Simplu3D** [4] in order to sample multi-dimensional building configurations.

This database will be released on dataverse[5] in order to offer the possibility to collaborate with urban planners to help them in regulation design or to provide high-dimensional data to computer graphics or graphical interface researchers.

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[3] Website of OpenMole project: http://www.openmole.org/

[4] Website of Simplu3D project: https://github.com/IGNF/simplu3D

[5] http://dataverse.org/

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