Towards a 3D geographic information system for the exploration of urban rules: application to the French local urban planning schemes

ABSTRACT: This paper presents the use of a 3D GIS to represent, analyse and explore the most common urban rules described in French local urban planning schemes. As these rules are only expressed in free formed texts, it is difficult to assess their impact on the city evolution. A schema is proposed in order to allow the capture and the management of urban rules. These rules are applied to a structured geographic environment in order to automatically determine and to represent their influence by 3D volumes. These volumes can be use by visual analytics to asses or emulate the influence of the rules in terms of buildable potential or by spatial analysis to determine their influence on the FAR (Floor Area Ratio) or to integrate pre-project building shapes.

1 Introduction

The development of the French territory is elaborated through large and complex sets of documents, planning or schemes (Territorial Coherence Schemes (SCoTs), local urban planning schemes (LUPS), Urban mobility plans (PDU), etc.). These documents illustrate strategies of urban and territorial development but they also are the expression of these strategies through several different constraints that projects are subjected to. The underlying logics refer to several domains (construction, housing, transport, urbanism, etc.) for which the pertinent level of detail is different. These difficulties and complexities highlight several issues and needs for planners such as new techniques to better understand, evaluate, manage and design the city (Bain, Maujean, and Theys 2008).

In the past, different works model the urban environment at different scales through different properties during the design process. Such declarative modelling enables to provide tools for architectural or urban design (Donikian 1992; Desmontils 1995), to assess building volumes according to restrictions (Faucher 2001; Viet-Tung 2003; Shen and Kawakami 2004) or to take into account visual accessibility (Nivet 1999). (Murata 2004) proposed the use of a 3D GIS to visualise the state of a city, the capacity of urban blocks and to assess a construction project. (Gilles and Claudine 2005) proposed a 3D tool of visualisation of urban knowledge and the prototyping of projects to improve communication and to involve non-experts.

The goal of our work is to propose tools that integrate the specificities of urban knowledge linked to the urban rules of the French urban planning schemes. Graphic representation and the use of pertinent symbols to represent rules is another aspect of this work. Similar efforts are recently led (Caillaud, Denegre, Barbier, and Denis 2006) for the representation of such schemes on 2D maps.

2 A Tool to display and to explore urban rules

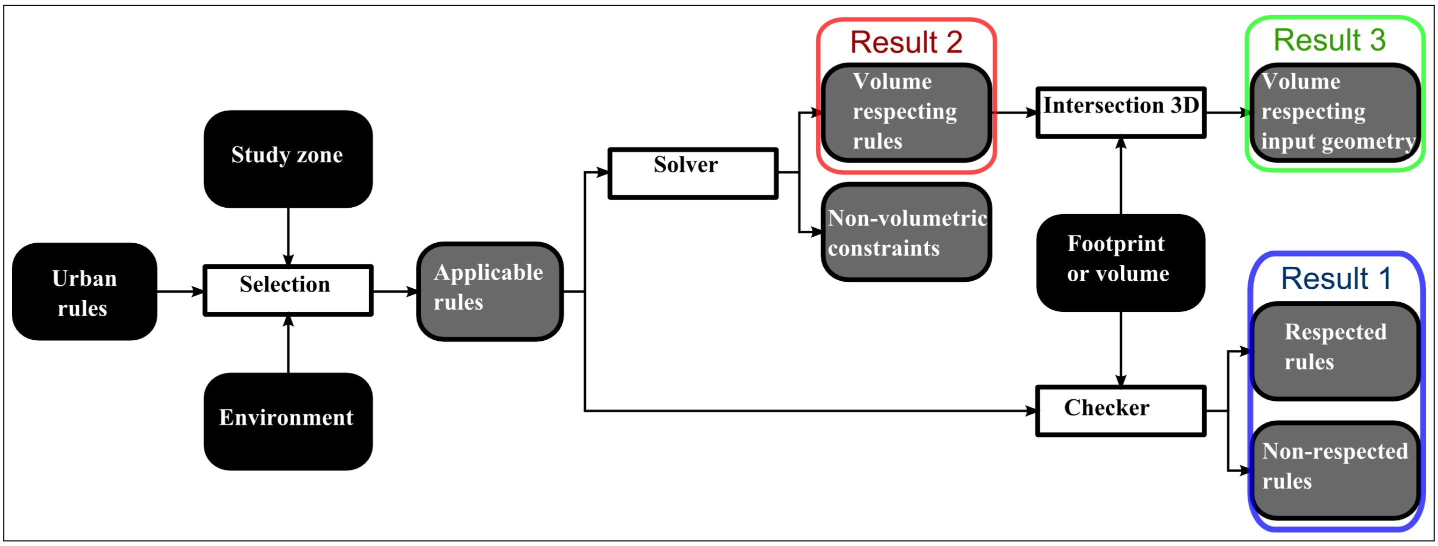

Figure 1: Global architecture of the application.

The aim of our application is to propose three kinds of functionalities as described in figure 1 :

1. checking the respect of a set of urban rules for existing or future buildings on a parcel,
2. visualizing constraints inferred from a set of rules by the mean of an automatically generated volume,

3. computing a volume that respects a set of rules and a 2D footprint or an imported building provided by a planner.

In figure 1, the different necessary inputs are presented. In order to study urban rules on an area, two pieces of information have to be modelled and integrated: the rules (*cf.* section 2.1) and the urban environment (*cf.* section 2.2).

2.1 The urban rules

The Local Urban Planning Scheme (LUPS)[1] is a document laying down regulations according to a global approach to develop an area. This approach is the expression of a urban project, including restructuring and development plans for the area, in full consultation with its citizens. Elaborated at the level of municipalities or inter-municipalities, LUPSs will eventually cover the entire French territory. Each LUPS specifies a zoning plan where each zone is affected to a type. The typology of zones includes urban zones (type *U*), zones to be urbanised (type *AU*), agricultural zones (type *A*) and natural or forested zones (type *N*), which can be declined into subtypes (type *UA* for residential urban zones for instance). For each type (or subtype) of zone, 14 articles have to be defined. These articles have the same titles for all LUPSs (for example, article number 10 always concerns buildings' height) but their contents are free so that each municipality can express its own set of customised regulations. Therefore, an important diversity exists in the expression of the rules of a same article in different LUPSs and one cannot pretend to formalise all possible LUPS rules.

Title of the article	Constraints considered
Forbidden or allowed land uses Land uses subjected to particular restrictions	Aspect of the building's facades Building functional use
Building implantation in relation with roads	Distance between a building and a road
Building implantation in relation with parcel limits	Distance between a building and a parcel Buildable 2D surface
Building implantation in relation with other buildings	Minimal distance between 2 buildings
Building footprint	Footprint max area
Building maximal height	Maximal height of a building Difference of height between 2 buildings
Exterior aspect	Material choice of roofs and walls Roof slopes
Floor Area Ratio (FAR)	Limit values of the FAR

Table 1: Rules implemented in our prototype.

As a matter of fact, in this paper, only a selection of articles has been considered. This selection is twofold: it concerns the nature and the granularity of the objects the rules relate to. The first selection is linked to the focus of this study: buildings' implantation. Therefore, articles concerning parking places or green spaces were filtered out. The second selection comes from the limitations of the available databases. Indeed, rules relating to elements of buildings such as balconies were kept out of the study because of the difficulty of acquiring and maintaining reliable data at such a granularity on large areas.

Finally, we propose a schema for expressing the rules. This formalisation limits the range of the rules that can be represented. Indeed, only the most common expressions of these rules were kept. Further work is required to explore the impact of this limitation and the extension of the formalisation to include a wider range of rules. Table 1 presents the main articles and rules that were selected. LUPS refer to geographic information and relationships which have to be implemented in the system to exploit the different rules. For instance, in some rules, the distance of a building to a road border may depend on the width of this road: the knowledge of the width of roads is necessary to use this rule.

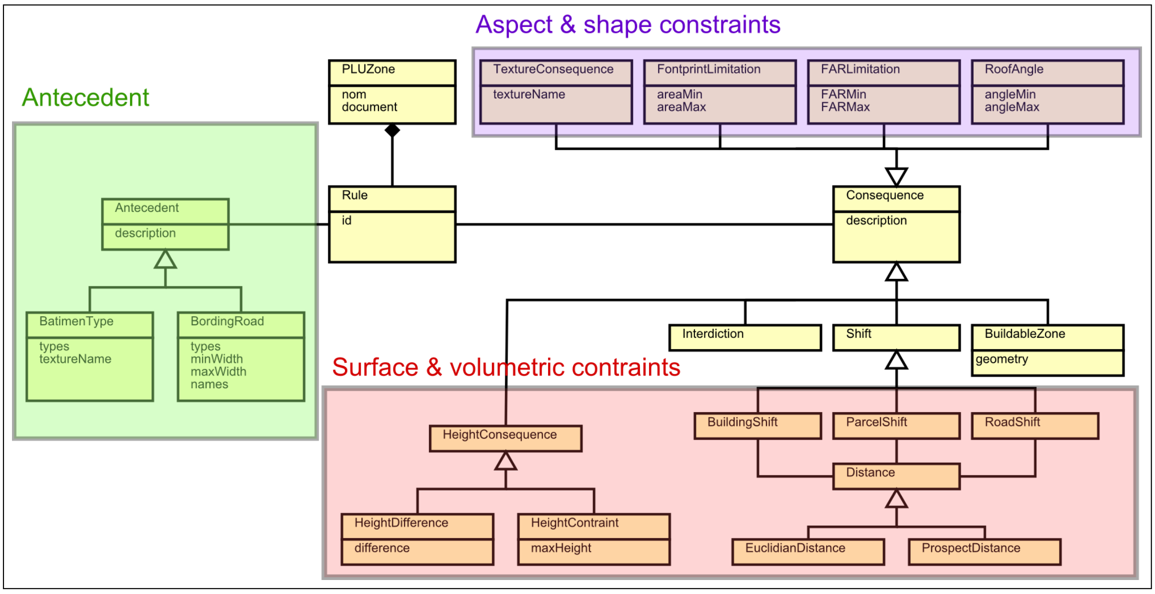

Figure 2: Schema of the elements of rule considered.

Selected rules can be formalised from the different elements identified in the study. This formalisation transcribes the logic of the administrative partition: a set of rules is defined for each type (or subtype) of zone. Once defined, a rule can be applied to a parcel associated to the type (or subtype) of zone.

[1] Plan Local d'Urbanisme (P.L.U.) in French

A rule is composed of a condition and a set of constraints (as a consequence of the condition). Thus, if no condition is defined for a rule, the constraints always apply (i.e. for all parcels associated with the considered type of zone). Otherwise, the condition must be met for the constraints to apply. For instance, let us consider the following rule (in green the condition and in red the consequence):

If the width of a road is smaller than 7m **then** distance between the borders of this road and buildings must be higher than 3m

will only apply to parcels with an adjoining roadlarger than 7 meters.

The modelling of rules in our tool is presented in figure 2l. The classes of conditions and of the different kinds of consequences we consider are represented. We classify the different elements of rules as follows:

Conditions Conditions are divided into two categories:

- conditions concerning the properties of the road adjoining the parcel
- conditions concerning the properties of the constructions in the parcel

Constraints Constraints are divided into four categories:

- volumetric constraints concerning limitations on volumes in which constructions are allowed in the parcel
- surface constraints concerning the surface of the constructions in the parcel (either of the footprint or the total area of the buildings' floors)
- shape constraints concerning specific shapes of certain elements of the constructions in the parcel, especially roof slopes
- constraints on the aspect of the constructions in the parcel (mostly concerning materials)

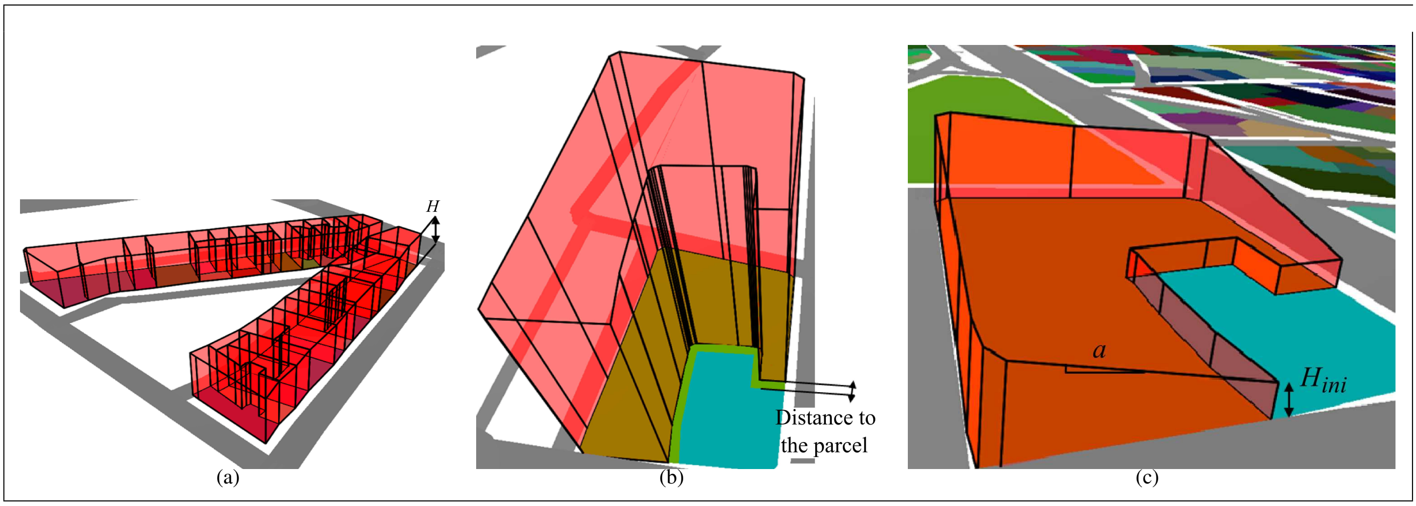

Figure 3: **(a)** Limitation of a maximal height H for a set of parcels. **(b)** Minimum distance to the cyan parcel. **(c)** Prospect distance from the cyan parcel with a slope s and height against road $Hini$.

Volumetric constraints allow the creation of the maximal buildable volume. In the rest of this article, we focus on rules estimated particularly relevant for 3D analysis :

Maximal height of a building : The aim of these rules is to limit the maximal height H of buildings on a parcel (*cf.* figure 3(a)). This means that the building geometry should be included in a solid processed from the extrusion of a parcel with a value H.

Floor Area Ratio (FAR) : The FAR is calculated from the livable surface of a building (surface of all the levels deducted by the surface of technical units, isolation, etc.) divided by the parcel surface.

Distance between a feature (adjoining road, neighbouring parcel or building) : These rules contraint the distance between a construction and another feature. Two kinds of distance are used in our application (*cf.*figures 3(b) et 3(c)) : the *Euclidean distance* and the *prospect distance*. The Euclidean distance indicates at which distance from a feature a construction can be implanted. The prospect distance is expressed through an affine equation whose maximal height limit depends on the distance to a feature : $D = s \times H + H_{ini}$, where s is a positive coefficient (the slope) and H_{ini} the maximal height to respect at the border of the feature.

2.2 Geographic schema

In order to allow reasoning on a set of urban rules, geographic features, mentioned in LUPS, are organised in our approach according to a conceptual schema (*cf.* figure 4). This schema only contains the required information for the proposed application to building implantation (objects such as natural areas or electrical wires are not included). For instance, evaluating the FAR requires knowing which buildings a parcel contains. As this schema is quite generic, several datasets can be use to describe the urban environment.

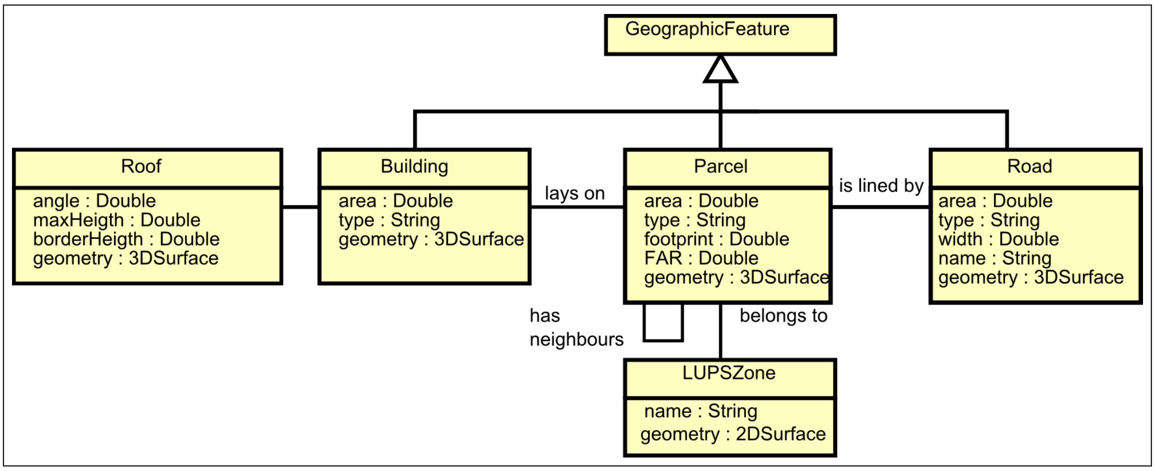

Figure 4: Schema of the considered objects of the urban environment.

3 Implementation

In order to implement such a system, it is necessary to create tools to format the inputs as described in our internal schemas. That concerns rules (*cf.* section 3.1) and the geographic environment (*cf.* section 3.2). The technical choices of the application are described in this part (*cf.* section 3.3).

3.1 Graphic user interface dedicated to rule creation

A graphic user interface is devised in Java in order to capture and to export rules according to our schema (*cf.* figure 5). The JAXB (Java Architecture for XML Binding) library is used to implement our conceptual schema from a schema file (.xsd) and to save corresponding data in XML format. The interface is a main window for filling in information about the LUPS zoning plan. It is possible to add or delete new rules. Another window enables the edition of rules: possibility to add conditions and consequences and to fix their parameters.

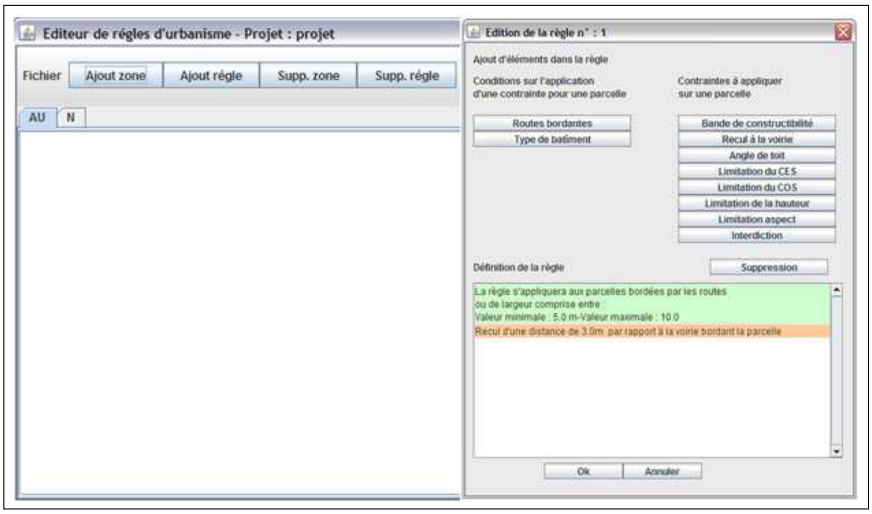

Figure 5: Screenshot of the graphic user interface dedicated to rule modelling.

Furthermore, in order to ease its handling, a textual description of each rule element is generated during its use. The exported XML file contains this description for a better understanding of its content.

3.2 Integration and data loading

A pre-treatment, processed during data loading, enables to initialize relationships between a parcel and buildings it contains (a building can spread on only one parcel), between neighbour parcels and between a parcel and its surrounding roads.

In order to determine neighbourhood relationships between roads and parcels, it is necessary to know the geometry of the borders of the roads. Nevertheless, in some databases, roads are modelled with a linear geometry (the road axis). In this case, the geometry of the borders is approximated by applying a buffer whose size corresponds to the attribute *width* of the roads. The link between a building and its roof is directly extracted from imported data. The application can directly represent and query in the 3D navigator relationships in order to check if the pre-treatment is successful.

3.3 System

A urban environment and a file of rules as described in the previous section are used as input of the application. The process is then applied on a set of parcels selected by the user. Functionalities presented in this article are developed on the open-source GIS platform *GeOxygene* (http://oxygene-project.sourceforge.net/) (Brasebin 2009). This platform implements the ISO 19107 specifications that describes geometric schema (ISO 2003). It provides notably tools to load data (Shapefile format, CityGML, etc.), 3D geometric functions (Boolean operators, extrusions, etc.) and a viewer (the different pictures of this article are screenshots from GeOxygene).

4 Results

Different results of the use cases of our application are presented in figure 1.

4.1 Presentation of the studied area

In order to illustrate more practically our results, the different processes presented in the next section are applied on a specific area. This studied area is located at the centre of Paris with a high-density of buildings (figure 6(a)). The interest of this area is to determine its potential in terms of buildable area to assess the possibilities of densification in accordance to the LUPS regulation. This LUPS is expressed through several atlases: zoning atlas, general height atlas, risk atlas and a synthesis atlas, that contain specific planning processes. The zoning plan of Paris is composed of a urban general zone (UG), a urban zone of services and natural zones. Our study zone is located in the UG area. The maximum building height is expressed by two atlases: the general height atlas, that defines for a district a maximal height, and a 1/2000 map that conveys information about prospect distance on parcels according to the adjacent roads (figure 6(b)).

(a) (b)

Figure 6: **(a)** 3D representation of the studied area. **(b)** Height plan of the studied area and its legend.

The following rules are modelled in our application:

- Minimal distance between 2 buildings on a single parcel is 6 m
- Minimal distance to the parcel border is 0 m
- Maximal FAR value is 3
- Prospect distance is applied according to the 1:2000 map
- Maximal height is 25 m

The study area was described through 3 different datasets of the Institut Geographique National (*cf.* figure 7) :

- **buildings**, are from BATI-3D dataset. It contains 3D buildings with roofs in the CityGML format,
- **parcels**, are loaded from the BD PARCELLAIRE dataset. In this dataset, all cadastral parcels for the entire France can be found,
- **roads**, are imported from BD TOPO dataset. It covers French territory at the 1/25,000 scale and geometries are described as 3D lines.

Empirically, to calculate FAR, the liveable surface is obtained by using 80 percent of the surface of all the building levels. Furthermore, we consider that the height of a level is 3m in order to determine the number of levels (and so the surface of all levels) as this information is not described in our database.

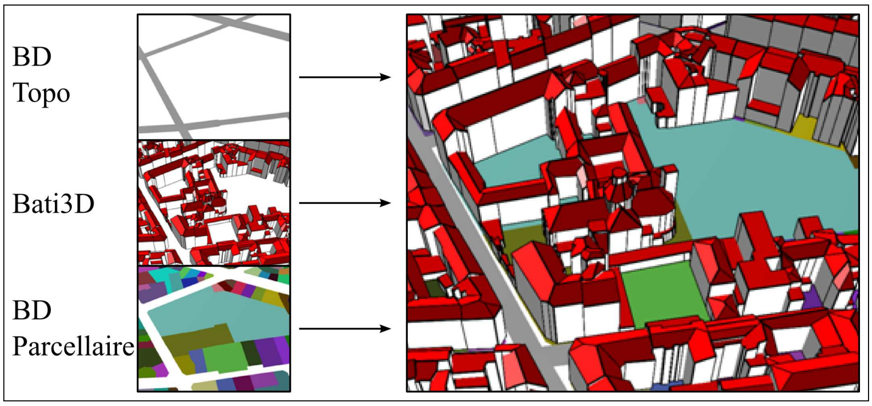

Figure 7: Layers composing the urban environment.

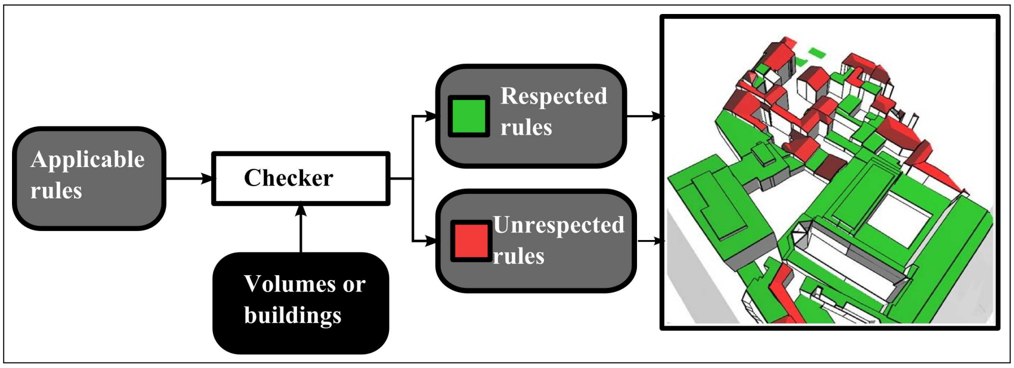

Figure 8: Verifying a rule that concerns the roof angle.

4.2 Verification of rules of a LUPS

The first result presented (*cf.* figure 8) is the checking of rules from a LUPS on a set of parcels. The application tests for a collection of parcels if rules concerning the buildings (real or emulated) of a parcel are satisfied or not. At the scale of a parcel, this enables to verify if a new project respects the different constraints imposed by the LUPS. At the scale of a district or a city, this functionality is useful to visualize the less respected rules in anticipation of a modification of the LUPS.

Results are two-fold. Each parcel is automatically associated with a list of rules that are respected and another one of rules that are not respected. Moreover, a layer containing located rules violations is created. This layer enables the user to zoom on a particular violation and to visualize it thanks to an adapted representation. For each kind of rules, a specific representation is defined.

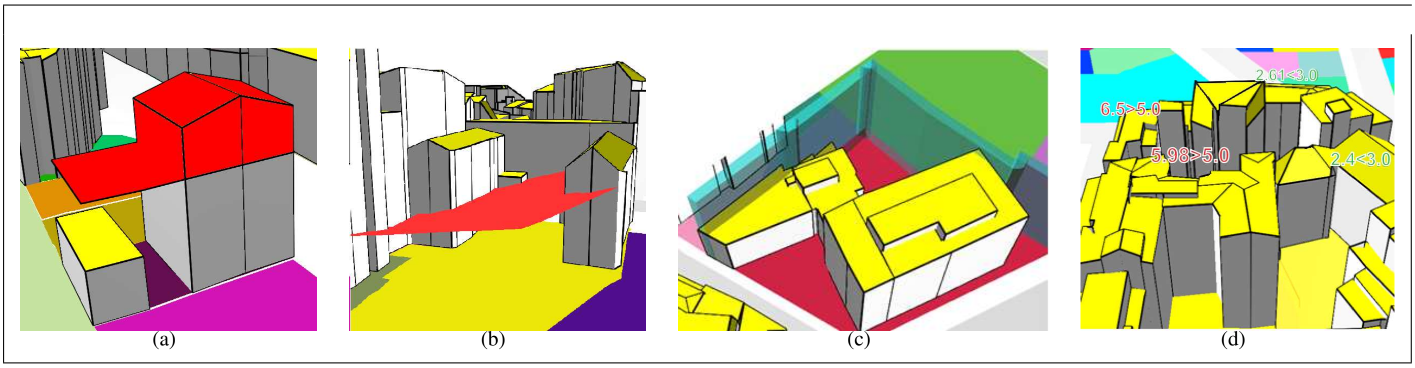

Figure 9: Representation of some un-respected rules. **(a)** Maximal height. **(b)** Prospect distance from the limit of the parcel. **(c)** Euclidean distance from the border of the parcel. **(d)** Maximal FAR value.

Different tests have been led to determine the representation of unrespected rules. Violations of rules linked to prospect distance or to maximal height are represented by a plane whose altitude is set according to maximal height allowed (*cf.* figures 9(a) et 9(b)). This representation enables to distinguish easily the parts of the volume that respect the constraint and the parts that do not respect it. Violations of rules that concern Euclidean distance between features, are represented by a volume with a certain coefficient of transparency corresponding to a non-buildable zone (*cf.* figure 9(c)). It is thus possible to detect parts of a building that do not respect the rule by noticing modification of color on the buildings faces. The textual display presented in figure 9(d) means if the FAR is not respected (a green text if it is small enough and a red one if it is too high).

Some results of rules verification on the studied zone are presented in figure 10. A 3D extract of our scene after verification processing is shown in figure 10(a). With a glance at this scene, three kinds of rules are noticeable unrespected :

- maximal height : the value is sometimes transgressed but buildings are never a lot higher.
- prospect distance : this rule is unrespected near roads whereas parts at the opposite of the roads respect it.

- maximal FAR : this rule is globally unrespected such as presented in figure 10(b). This is explained by the fact that recently maximal FAR decreased from 3.5 to 3.0 and because a large part of the buildings of this area is very old.

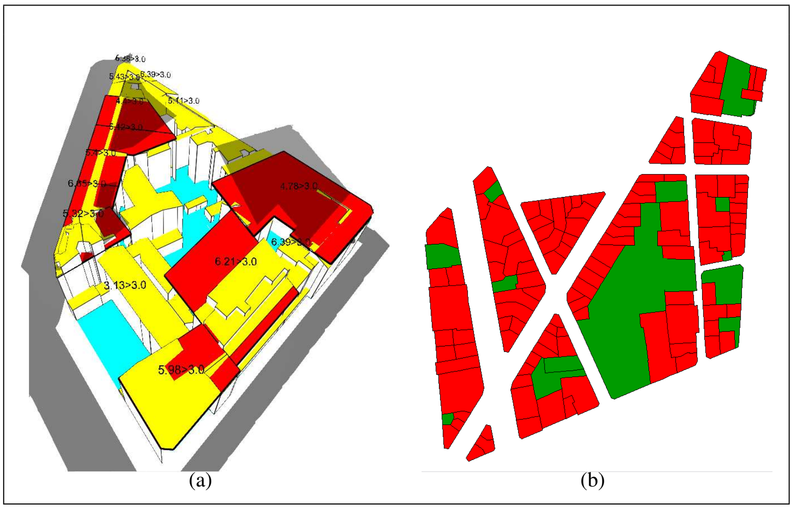

Figure 10: **(a)** Representation of unrespected rules on an extract of the study zone. **(b)** Parcels in red have a FAR higher than 3.

4.3 Calculation of a volume in respect with urban rules

The second presented functionality is the automatic evaluation, from a set of applicable urban rules, of volumes that respect inferred geometric constraints. We consider here only the volumetric constraints. The other constraints do not permit to directly deduce their influence on the maximal buildable volume (such as for example, the roof angle). The application can handle four types of non volumetric constraints : roof angle, material used, FAR and footprint area limitation.

This functionality described in figure 11 enables to visually take into account the impact of a LUPS or of its variation on non-built parcels.

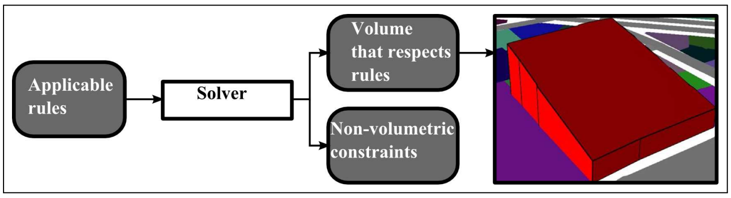

Figure 11: Creation of a volume that respects a set of rules.

The determination is processed through a solver (*cf.* figure 12) that uses geometric operators. Some 3D necessary functions, such as 3D intersection, are time consuming, that is why a strategy was developed to limit the repetition of this kind of operations.

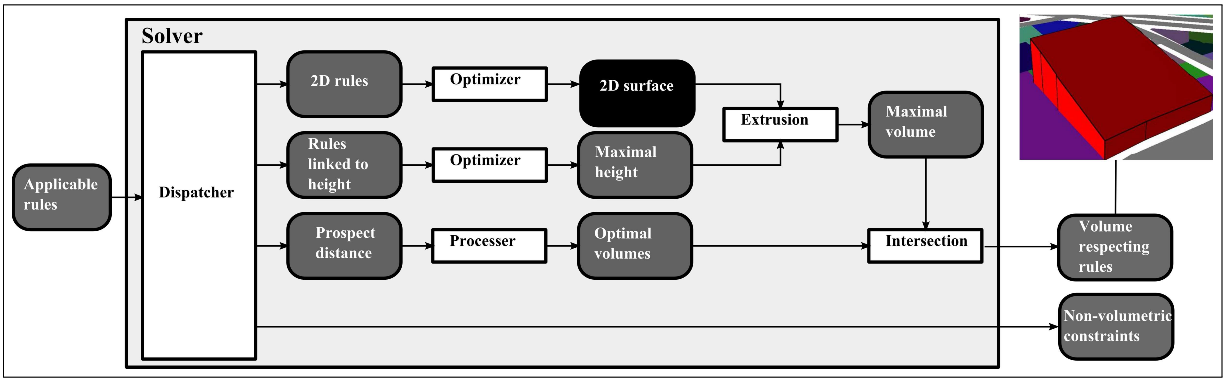

Figure 12: Solver organisation.

The first step consists in sorting the different rules that can be applied on a parcel. Rules are sorted in four categories and are processed in this order : 2D rules, height rules, rules about prospect distances and non geometric rules. *2D rules* limit in 2D the buildable surface of a parcel (Euclidean distance between features and imported buildable zones). They are processed together to define a buildable sub-surface of a parcel. Let us specify that the surface of existing buildings on the parcel is considered as non-buildable. If the result is a multi-geometry, each element is treated separately. *Height rules* limit the height of buildings and the difference of height between buildings on a same parcel. Thus, the maximal height of a parcel can be deduced. Thus, this information can be checked once the buildable volume generated. *Rules about prospect distances* generate a volume that corresponds to the mathematical definition of these rules (*cf.* section 2.1). Several volumes can be generated on a same parcel if this kind of rules is

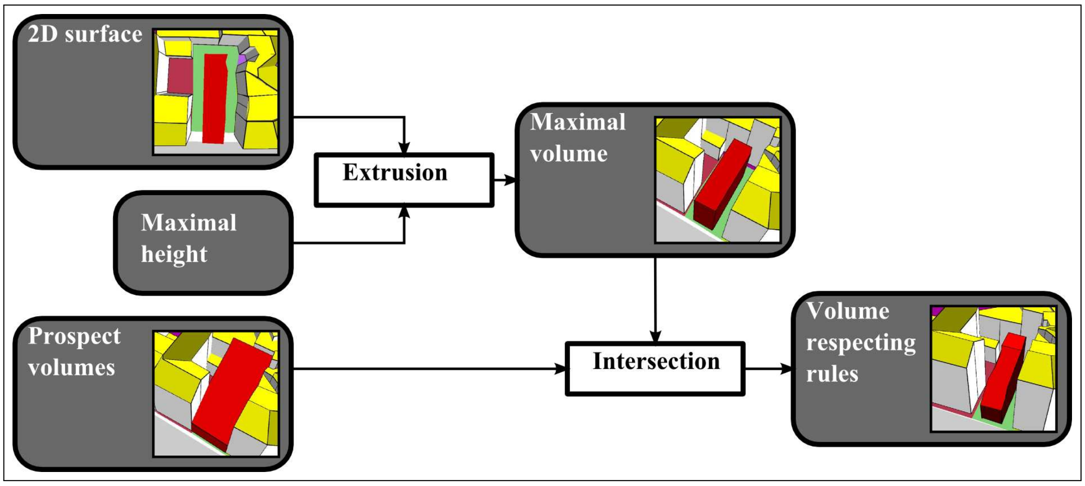

Figure 13: Steps to generate a buildable maximal volume on a parcel.

defined for the different features from our urban environment. *Non volumetric rules* currently do not directly influence the final result in this work as they don't enable to produce a unique solution.

In order to generate, a final maximal buildable volume, a first volume is obtained by the extrusion of the 2D buildable zones of the parcel according to height rules. The volumes are then intersected by the set of volumes obtained by rules about prospect distances to process the final volume. The figure 13 presents the different steps of the generation of a final volume with the following set of rules : 15m as maximal height, prospect distance with 5m as maximal height against the road and a coefficient (a) of value 2, minimum distance to parcel borders of 4m and minimum distance to road of 2m.

This process was applied on our area of study with the selected rules presented in 4.1. Results are presented in figure 14, they only integrate volumetric constraints. They provide a good way to visualise the potential impact of adding new buildings in this area.

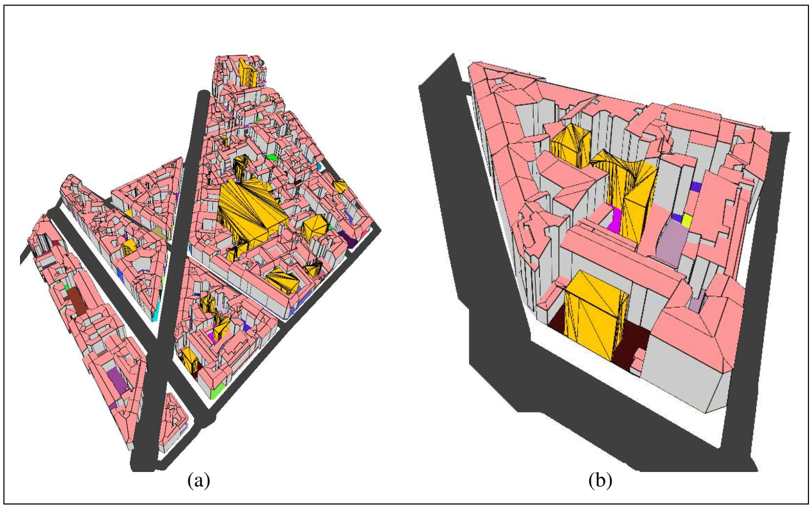

Figure 14: Views of buildable volumes (orange) according to the study case. **(a)** Global view of the zone. **(b)** Zoom on a sub zone.

These results can be better used in addition with a map of buildable areas (figure 15(b)). 3D processes enable to produce this map thanks to the FAR assessment and enable to determine which zones have a sufficient buildable potential to receive new buildings. Thus, with these two results, it is possible to know automatically which parcels have a building potential, an assessment of the cumulated area of floor that can be added on a parcel and the volume that must contain new construction(figure 15(c)). In our zone of study, some of the buildable volumes spread on parcels with a sufficient buildable potential, this result will be used in the next section to integrate some propositions of new constructions. We can notice the presence of a parcel (on the bottom right of the zone) with a sufficient buildable potential whose buildable volume is null: its FAR is lower than the maximal limit but no construction can be added due to urban rules (notably distance between buildings on a same parcel). Nevertheless, it seems possible to raise the buildings of this parcel to densify it.

4.4 Use of a maximal volume in a pre-project phase

The results of the previous functionalities can be perceived as rough, they process some results whose shapes do not look like "real buildings". In order to provide some help for pre-project phase, the possibility to cross the information of the maximum buildable volume with proposition from users is offered. Two options are available : the use of building footprints or the import of a 3D building. Thus, our application proposes a final solid that respects the input geometry and a set of applicable rules (*cf.* figure 16).

In our case study, we captured a set of footprints from our 2D map of buildable areas (figure 17(a)), that is useful to draw shapes in accordance with our urban rules. To produce 3D volumes, the system assesses the maximum number of levels allowed in respect with the FAR limitation (considering 1 level = 3m) and extrudes the footprints. Finally, final volumes, that respect rules and initial shapes, are produced by the intersections of these extrusions and the maximal buildable volumes (figure 17(b)). The map of buildable

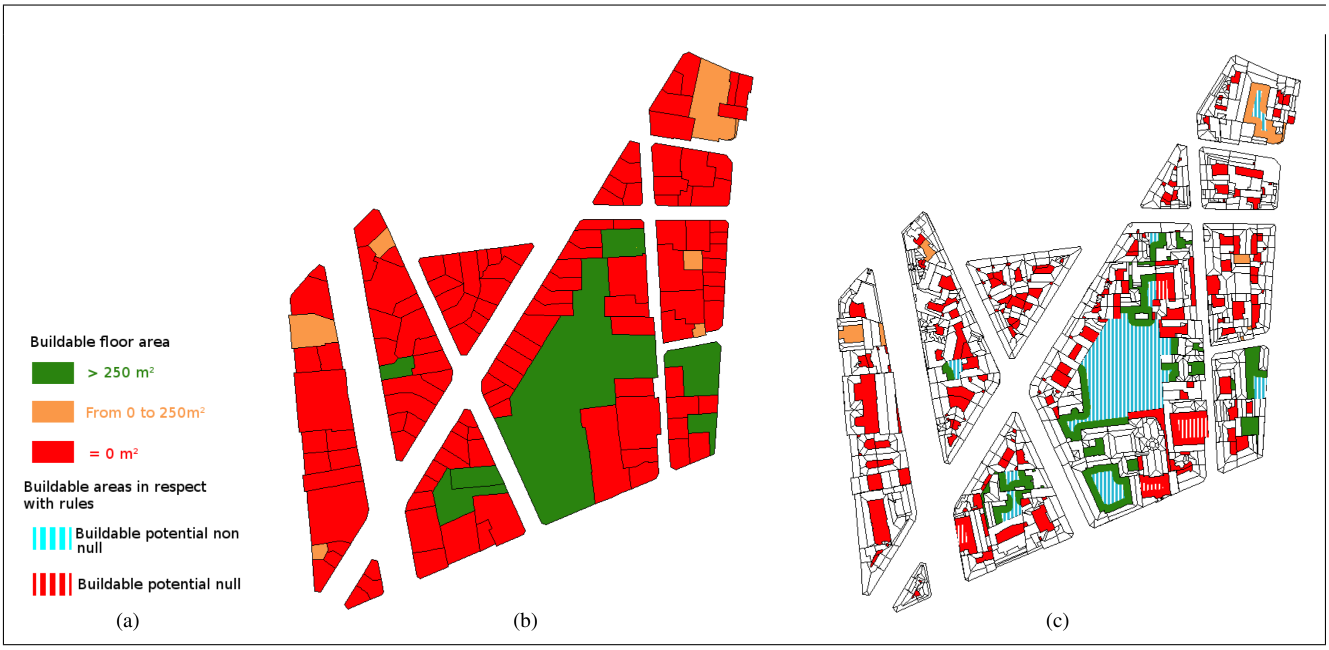

Figure 15: Map of buildable areas in respect with FAR limitation. **(a)** Legend of the maps. **(b)** Map of parcels. **(c)** Map of parcel with buildings and buildable volume in 2D.

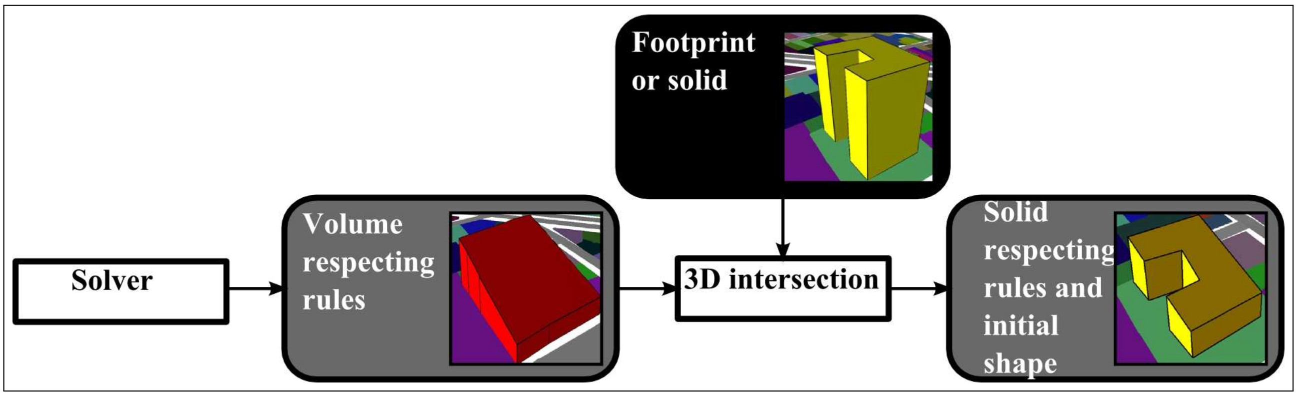

Figure 16: Optimal volume calculation from a building footprint.

area can be updated with our zone enriched by the new buildings (figure 17(c)). An important decrease of the buildable potential can be notified without reaching the maximal FAR.

This function provides a global overview of what could be a project in such a zone regarding these constraints. Furthermore, theses shapes can be considered as possibilities to explore during the creative conception work of the planner as mentioned in (Edmonds and Candy 2002).

5 Conclusion

This paper proposes a tool that permits the integration of most common rules of the French Local Urban Planning Schema (LUPS) and to exploit them with 3D spatial analysis. The application enables the 3D visualisation of the impact of urban rules, checks if they are respected and provides the integration of new projects. The 3D GIS is used as a pertinent tool to better comprehend the urban environment (notably about height rules) and regulation constraints.

Our aim is to provide a tool that can help during conception, discussion and decision phases in the context of urban projects. The LUPS is in France a reference document and such a tool can not be substituted to current administrative procedures. Nevertheless, our process requires the formulation of the rules of the LUPS and offers interesting experiences about the definition of the rules to detect some possible ambiguities. At terms, the integration of the temporal evolutions of these rules should enable to study their impact on the evolution of territory in a platform of simulation of urban dynamics (Perret, Boffet Mas, and Ruas 2009; Curie, Perret, and Ruas 2010; Perret, Curie, Gaffuri, and Ruas 2010).

Currently, this work is implemented as a prototype. Information about non-geometric constraints is not exploited, even if they can be reused in the checker. A reflexion about adding some knowledge to integrate these elements is actually led. Lots of perspectives are thus possible, for example in order to produce more detailed single buildings. The textures could be used by the application of non-photorealistic textures chosen in a library of type-textures. A user can indicate a footprint and thanks to the FAR, the application can deduce a possible building. It can be possible to use the limitation about the roof angles to generate a CityGML LOD2 building from a footprint by processing its skeleton.

The approach and the tool proposed are tested through the integration of some LUPS, and validations with experts of the domain (planners, municipalities, geographers etc.) will occur in the future. Tests show that some rules are missing such as the alignment of buildings on a zone. These ones should be added in the application. Furthermore, the addition of new rules can become very pertinent if more accurate semantic or geometric data is available (for example, presence of balconies, chimneys, functions of buildings etc.).

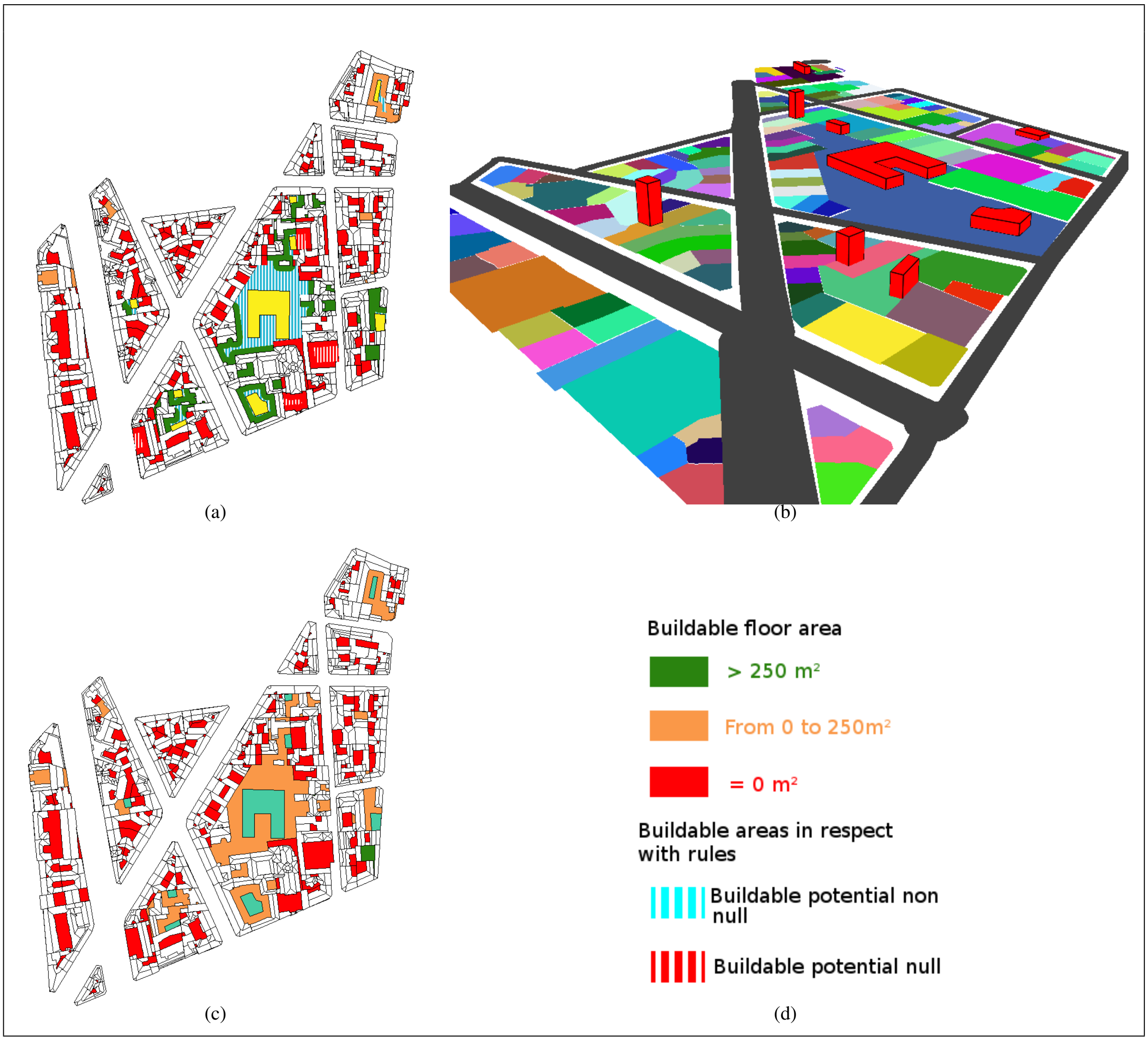

Figure 17: **(a)** Footprints of new proposition of building shapes in yellow on the 2D map of buildable volumes. **(b)** View of the 3D shapes, in red, generated by the application.**(c)** Buildable floor area enriched with new propositions of buildings with 3m levels. **(d)** Legend of the maps.

Terrestrial imageries acquired from vehicles (Devaux, Paparoditis, Precioso, and Cannelle 2009) and information extracted from them (such as wall openness (Hammoudi, Dornaika, Soheilian, and Paparoditis 2010), ground marks or signs (Soheilian, Paparoditis, and Boldo 2010)) opens new perspectives for the use of 3D GIS for conception, discussion and decision making around urban projects.

To complete this work, a reflexion about the impact of our simplifications on the quality of the results will be led. The study will first focus on the impact of the use of the value $3m$ to determine the height of a level (notably for the assessment of the FAR), but also on the choice of our building (does the IGN 3D dataset for buildings supply more pertinent information than the 2D dataset ?) and road (notably for the road width) dataset. Our application enables to visualize interesting phenomena. But as virtual 3D is not always easy to understand a more global work about 3D semiotics in GIS can improve the visual effectiveness of our application.

6 Acknowledgments

This work is partly funded by clusters *Advancity* and *Cap Digital* through the *TerraMagna project*. It was realised in collaboration with *Bionatics* and the *IGN*.

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