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# ARCHITECTURAL RULES FOR THREE-DIMENSIONAL RECONSTRUCTION

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## ABSTRACT

The three-dimensional reconstruction of the urban fabrics has been the object of several studies and research. To lead to the acquisition of the geometry of architectural or urban sets, some of the studies were based on photogrammetry or vision by computer. Others use a laser providing a 3D scatter plot. Also, other research, were directed towards the development of CAD software. And some other research, carry on the automatic generation of 3D morphological representation resting on the exploitation of a base of architectural knowledge. The majority of these methods use expensive tools and complicated and long reconstruction processes.

Our method, contrarily to previous works, uses two-dimensional documents, primarily cadastral maps digitalized on computer. From these documents, we extract the relevant elements related to the third dimension which will be used together with the rules of town planning, for the 3D automatic reconstruction of urban fabrics.

Our method has been implemented in the “MEDINA” system and the first computer experiments were very promising.

## KEY WORDS

Three-dimensional reconstruction, Urban fabric, Modeling, Roofs.

## 1. Introduction

Cities are three-dimensional complex spaces on which we have most of the time only two-dimensional information such as cadastral plans, perspective drawings, photomontages or air photos, etc. But all these representations need a lot of time for their elaboration and implementation without filling all the needs of the designers. The representation by computer of the townscape constituted one of the new means on which an important research effort was undertaken these last years.

Some works succeeded in the production of tools allowing the restitution of urban sets geometry using

photogrammetry [1, 2, 3, 4] vision by computer [5, 6]. Others focused on the development of acquisition tools from a laser providing a 3D scatter plot [7, 8, 9]. Another group of research turned to the development of CAD software such as Allplan, Archicad, Palladio, Apdesign... Finally, some other works carried on the automatic generation of 3D morphological representation resting on the use of a database of architectural knowledge [10, 11]. The majority of these methods used expensive tools and complex and long reconstruction processes.

Contrarily to the majority of the present three-dimensional reconstruction methods which try to obtain an exact and precise 3D reconstruction of buildings of urban forms based only on technical mediums, the goal of this Paper is to present a new technique allowing the generation of three-dimensional urban fabrics representations using available documents (i.e. digitized cadastral plans), with simple and modest means, closer to the methods and knowledge of architects and town planners. This is why; we were interested in two elements of urban morphology which relate to our study: height of building and roofing. Then, we studied regulation and technical constraints relating to these two elements and we brought out the appropriate rules that had to be respected during the three-dimensional reconstruction process of the urban fabrics.

The developed method allows to solve and to generate the three-dimensional buildings geometry in the most frequent cases. The purpose of this work is not to acquire a definite morphology representation of a given urban fabric. The complexity of urban forms owed to history, techniques, architectural wills, climatic conditions, etc. is such that it would be presumptuous to pretend reaching it automatically. Our ambition is to generate credible urban volumes based on knowledge relating to the implementation and on town planning rules.

Algorithms resulting from our work are implemented in the “MEDINA” system. Our system allows the generation of 3D buildings geometry in the most frequent cases. The acquired models, in spite of their simple geometry, should be able to be useful in town planning studies when local

precision relating to architectures is not requested. We applied our system to the “Maxéville” (suburb of Nancy in France) cadastral plan, to the quarter of “Boudonville” in Nancy and to the quarter of the scientific campus in “Vandœuvre-lès-Nancy”. The obtained results were very promising.

## 2. Three-dimensional Reconstruction Rules:

There are two kinds of rules:

### 2.1 Rules regarding the height of the building

The number of floors and the height of the ground floor as well as the upper floors depend on historical periods and architectural styles (i.e. in a haussmannian fabric the height of the ground floor is 4.30 m and the height of each upper floor varies between 3 m and 3.40 m).

**Rule n°1:** The number of floors of a building, the height of its ground floor as well as the height of its upper floors depends on the historical period of its construction.

The introduction in our system of regulation height according to different regulation periods allows us to verify the values entered by the user.

Consider for example the city of Paris between 1784 and 1980 [12]. In the following, we note by  $l$  the breadth of the street and  $h$  the regulation height of the façade. We have:

- If the building is constructed between 1784 and 1859:
  - If  $l < 7,80$  m then  $h \leq 11,70$  m
  - If  $l = 7,80$  à  $9,75$  m then  $h \leq 14,62$  m
  - If  $l \geq 9,75$  m then  $h \leq 17,54$  m
- If the building is constructed between 1860 and 1884:
  - If  $l < 7,80$  m then  $h \leq 12$  m
  - If  $l = 7,80$  à  $9,74$  m then  $h \leq 15$  m
  - If  $l = 9,74$  à  $20$  m then  $h \leq 18$  m
  - If  $l \geq 20$  m then  $h \leq 20$  m
- If the building is constructed between 1902 and 1966:
  - If  $l < 12$  m then  $h \leq 6 + l$
  - If  $l \geq 12$  m then  $h \leq 18 + (l - 12/4)$
- If the building is constructed between 1967 and 1980:
  - If  $l \leq 12$  m or  $l \geq 30$  m then  $h \leq l$
  - If  $12$  m  $\leq l \leq 30$  m then  $h \leq l + 3$  m

**Rule n°2:** The regulation height of the façade of a building depends on the age of the building and on the breadth of the street allowing access to it.

### 2.2 Rules regarding the roofing of the building:

Let us consider first the rules concerning property borders. To produce these rules, we analysed all possible positions of a building with respect to its borders. We first treated the cases of simple buildings (square or

rectangular forms), and then the cases of buildings with composed forms (we were interested in L, T and U forms). We consider two types of property borders: the borders on joint ownership and borders on public street (see Fig. 1, 2, 3).

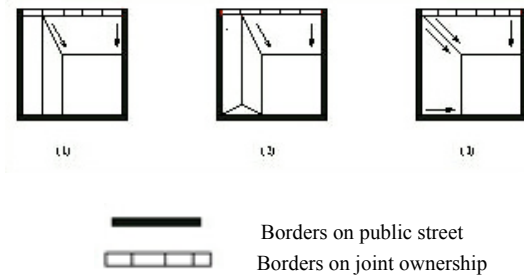


Fig. 1. Case of an L shaped building associated with three borders of ownership overlooking public street

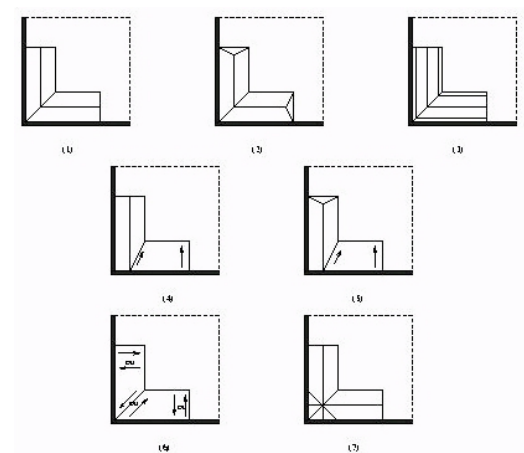


Fig. 2. Case of an L shaped building associated with two borders overlooking adjacent public street

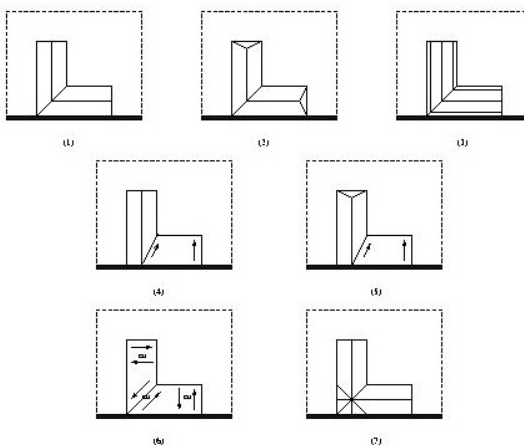


Fig.3. Case of an L shaped building with one border of ownership overlooking public street

The different positions of a building with respect to the separating borders lead to a variety of types of roofing. Since pluvial waters cannot be evacuated on the neighbour plot, only the joint ownership border influences the type and the form of the roofing.

**Rule n°3:** When a building is associated with a joint ownership border, the sewer of the tipped up panel of its roofing should not be on the side of this border.

If we have several possible forms then we define a new rule:

**Rule n°4:** Introduce an order for the selection of roofing forms.

The introduction of roofing regulation height in the system allows us to check the values entered by the user.

**Rule n°5:** The regulation height of roofing depends on the historical period of the building and the breadth of the public street allowing access to the building.

Every type of material leads to a narrow range of values for the slope of the roofing [13]. We can introduce these values into our system as an additional control tool. For example:

- If the roofing is constructed in tile then  $14^\circ \leq \text{slope} < 60^\circ$ .
- If the roofing is constructed in slate then  $11\frac{1}{3}^\circ \leq \text{slope} < 90^\circ$ .
- If the roofing is constructed in wood then  $20^\circ \leq \text{slope} < 48^\circ$ .

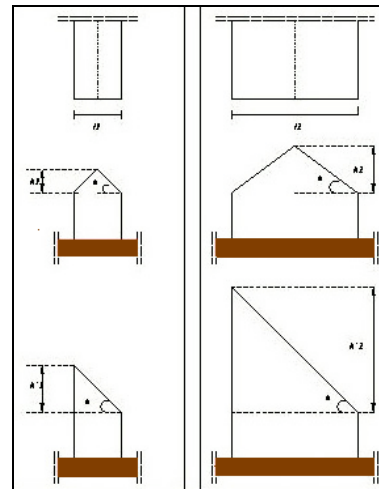
**Rule n°6:** The slope of roofing depends on the material Used.

According to Rule n°5, there is a maximum regulation height of roofing, and according to Rule n°6, there is a minimal angle of the roofing slope. To respect these two rules, the range of roofing must be less or equal to a maximum value.

If we consider for example a building 6 metres wide ( $l_1 = 6\text{ m}$ ) with a minimal slope ( $\alpha$ ) of 45 degrees, the height of the roofing is going to be equal to 3 m for a two-panel roofing and to 6 m for one-panel roofing. But if we consider a building 20 metres wide ( $l_2 = 20\text{ m}$ ) with the same minimal slope ( $\alpha$ ) of 45 degrees the roofing will have 10 m height for two-panel roofing and 20 m height for a one-panel roofing (see Fig.4).

These two examples show that for the same slope of roofing, we can have heights of different roofings which depend on the breadth of range. Therefore, if the breadth of the range of roofing is not restricted, the height of the roofing can exceed the regulated height which can cause technical or architectural problems. For this reason, we must introduce a restricted value for the range of roofing that must be respected during the reconstruction process.

**Rule n°7:** Introduce an acceptable maximum value for the range of roofing.



**Fig. 4.** Influence of the roofing range on its height according to its form (roofs with 1 and 2 panels)

There are other types of composite roofing which are more complex. The complexity of these types comes mainly from the form of the building and the difference between the breadths of its different wings. Let us consider a T shaped building with two wings of different breadths  $l_1$  and  $l_2$  (see Fig.5). If we take a constant angle for both bodies of building, then we will have roofings with different heights ridgepoles (see (1) of Fig.5). To acquire (according to our limitative working hypothesis) ridgepoles at the same level, it is necessary to use two different angles for both wings of the building (see (2) of Fig.5). As a result, it is important to introduce new rules determining the slopes of the roofing according to the breadth of the different wings of the building.

**Rule n°8:** If the ridgepole is continuous then the slope of roofing depends on the breadth of the different wings of the building

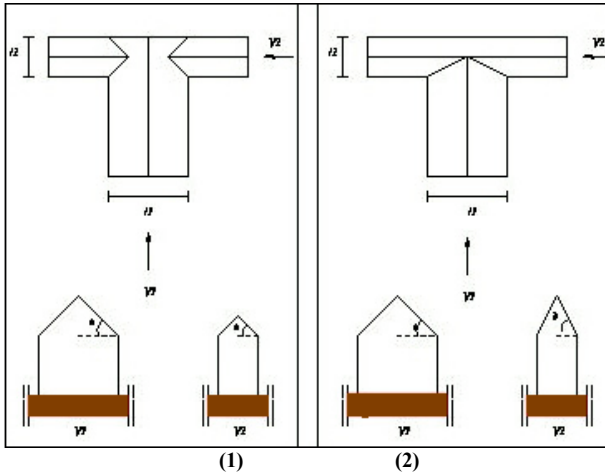


Fig. 5. Influence of the breadth of the wings on the roofing:  
case of a T-shaped roofing

- (1) constant angle - discontinuous ridgepole
- (2) different angles - continuous ridgepole

**Rule n°9:** If the angle is constant then the ridgepole of the building is discontinuous.

**Rule n°10:** If the angle is constant and the ridgepole is continuous then the sewers of the roofing have different heights.

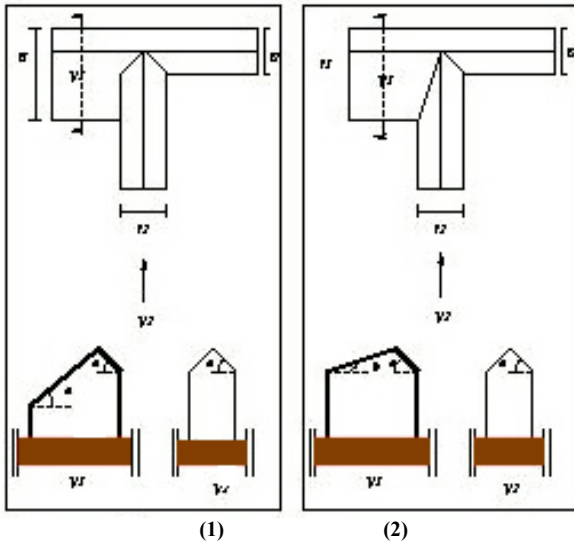


Fig. 6. Influence of the breadth of the wings on the roofing:  
case of a T-shaped roofing .

- (1) constant angle - discontinuous ridgepole
- (2) different angles - continuous ridgepole

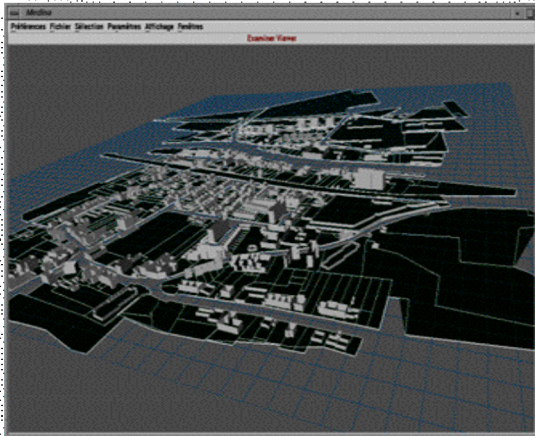
### 3. Implementation and Computer Experiments:

Our method regarding the three-dimensional reconstruction of the townscape was implemented in the “MEDINA” system which includes two main functions. The first one allows the reconstruction of the heights. It was implemented on Autocad using the Autolisp programming language. The second function of the system allows the reconstruction of roofs. It was implemented using the C++ programming language and the Open Inventor graphic library which is dedicated to the manipulation of three-dimensional objects.

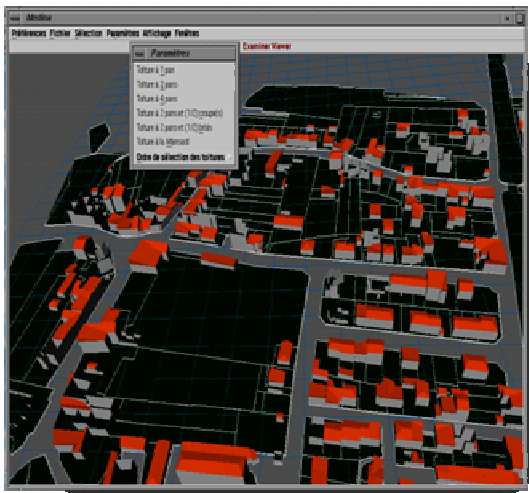
We have applied our system to the “Maxéville” cadastral plan (see Fig.7). We started by separating the various urban fabrics in order to put each of them on a different layer. Then we generated simplified volumes of the urban fabric. Let us mention that for every urban fabric, the only variable is the number of floors, since the height of the ground floor as well as the upper floors, which are entered by the user, are assumed to be the same for all the selected fabric. Once the reconstruction of the heights is done (see Fig.8), we call the function which allows the reconstruction of roofs (see Fig.9).



Fig. 7. Cadastral plan of Maxéville



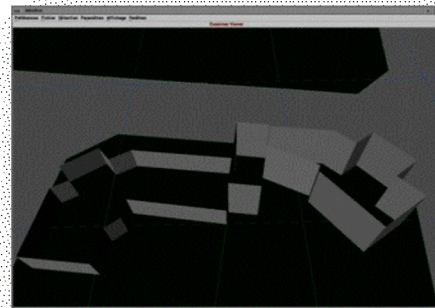
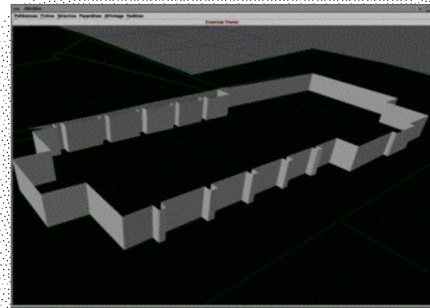
**Fig. 8. Reconstruction of the heights**



**Fig. 9. Reconstruction of roofing**

The application of our system to the “Maxéville” cadastral plan, to the quarter of “Boudonville” and to the quarter of the scientific campus in “Vandœuvre-lès-Nancy”, allowed us to recognize respectively 83%, 70% and 75% of polygons. “MEDINA” generated automatically for these examples the heights of all the buildings and about 98 % of roofs among the recognized polygons.

Roofs which were not generated by our system correspond to polygons of very complex forms or to roofs of specific forms (see for example Fig. 10). Let us mention that the percentage of the generated roofs which correspond to the reality varies between 88% and 91%.



**Fig. 10. Examples of non-allowed polygons**

The 3D models obtained with our system, in spite of their geometrical simplicity, are often widely sufficient for studies of town planning where the local precision relative to the architecture is not required.

#### **4. Conclusion:**

As opposed to the majority of technical methods allowing an exact and precise 3D reconstruction of buildings, we succeeded, by using available documents and a database of knowledge issued from urban legislation and technical rules, to implement a system allowing the 3D reconstruction of buildings.

This system should help the designers, town planners and architects, by giving them the possibility to obtain 3D urban fabrics starting from simple 2D data. In addition, our technique can also be useful in the field of image synthesis by allowing the computation of the interactions between the 3D virtual object and its photographed urban environment.

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