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Architectural knowledge for three dimensional reconstruction

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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 photogrammetric 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 system MEDINA. The experimental results have shown the originality, the simplicity and the reliability of our technique compared to related methods

Keywords: three-dimensional reconstruction, urban fabric, modelling, 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 to 4] or computer vision.[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, etc. 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

1 Al Khalil, O. & **Grussenmeyer, P.** (2002). Single image and topoly approaches for modeling buildings, International Society for Photogrammetry and Remote Sensing *V Symposium* (ISPRS)
2 Drap, P. et al (2003). Le projet arpenteur : Un outil de photogrammétrie architecturale à l'usage des architectes et des archéologues. Rapport d'activités de recherches
3 Guarnieri, A. et al (2004). Digital photogrammetry and laser scanning in cultural heritage survey, Proceeding of 20th ISPRS Congress, Istanbul, Turkey
4 Grussenmeyer, P. (2003). Photogrammétrie architecturale et modélisation 3D du patrimoine, Revue XYZ, 95, pp30-36
5 Sequeira, V. et al (2001). Hybrid 3D reconstruction and image-based

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 a system which 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[12] 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 Three-dimensional Reconstruction rules.

2.1 Rules regarding the height of the building

Regulations specifying height of buildings vary depending to countries, cities and periods of construction. They constitute an important tool to shape the city and its general appearance. It was an old preoccupation called *Non altius tollendi* servitude.

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 (Figure 1).[13]

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 (Figure 2and 2b)
  - **If** **l** < 7.80 m **then** **h** ≤ 11.70 m
  - **If** 7.80 ≤ **l** < 9.75 m **then** **h** ≤ 14.62 m
  - **If** **l** ≥ 9.75 m **then** **h** ≤ 17.54 m
- If the building is constructed between 1860 and 1884 (Figure 2c)
  - **If** **l** < 7.80 m **then** **h** ≤ 12 m
  - **If** 7.80 ≤ **l** < 9.74 m **then** **h** ≤ 15 m
  - **If** 9.74 ≤ **l** < 20 m **then** **h** ≤ 18 m
  - **If** **l** ≥ 20 m **then** **h** ≤ 20 m
- If the building is constructed between 1902 and 1966 (Figure 2d)

rendering techniques for reality modelling. SPIE, 4309

6 Curless, C. (1996). A volumetric method for building complex models from range images, Proceedings SIGGRAPH1996

7 Dekeyser, F. et al (2003). Relevé du patrimoine architectural par relevé laser, vision par ordinateur et exploitation des règles architecturales, Colloque Maquette virtuelle et patrimoine

8 Borghese, A. & **Ferrari, S.** (2000). A portable modular system for automatic acquisition of 3D-objects. IEEE Trans. On instrumentation and measurement, 49:5

9 Balzani, M. et al (2001). A terrestrial 3D laser scanner: Accuracy tests, Actes CIPA XVIII International Symposium., pp. 445-453

10 Koehl, M. (2004). 3D city models, geometric data structure for 3D urban GIS, 24th Urban Data Management Symposium, Chiogga-Venice, Italy

11 Mitchell, W.J. (1990). The logic of architecture, design, computation and cognition. MIT Press. Cambridge, Massachusetts

12 Suburb of Nancy in France

13 Atelier Parisien d'Urbanisme - APUR (1974). L'évolution des formes urbaines au travers des règlements traditionnels, Paris Projet N°13-14, pp.24-35

14 ibid
16 Editions Eyrolles, Editions Techniques (1998). Encyclopédie du Bâtiment, tome 2b, 3, Editions Eyrolles, Editions Techniques

If $\mathbf{l} < 12$ m **then** $\mathbf{h} \le 6 + \mathbf{l}$
If $\mathbf{l} \ge 12$ m **t** **hen** $\mathbf{h} \le 18 + (\mathbf{l} - 12)/4$

– If the building is constructed between 1967 and 1980 (Figure 2e):
If $\mathbf{l} \le 12$ m or $\mathbf{l} \ge 30$ m **then** $\mathbf{h} \le \mathbf{l}$
If $12 \text{ m} \le \mathbf{l} \le 30$ m **then** $\mathbf{h} \le \mathbf{l} + 3$ 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.

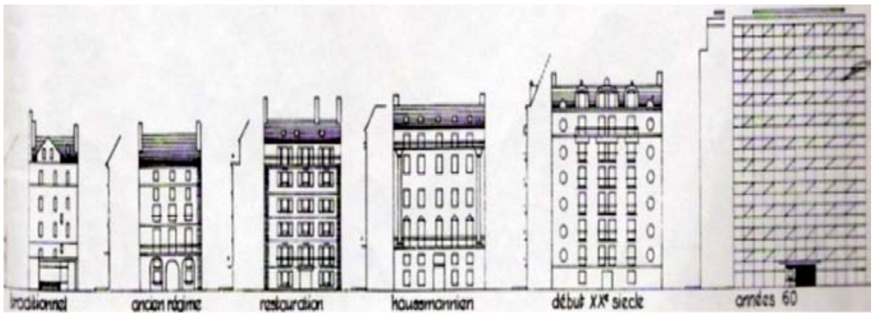


Figure 1 Evolution of the height of building according to historical periods [after APUR, 1974][14]

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 (Figures 3, 4 and 5).

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.

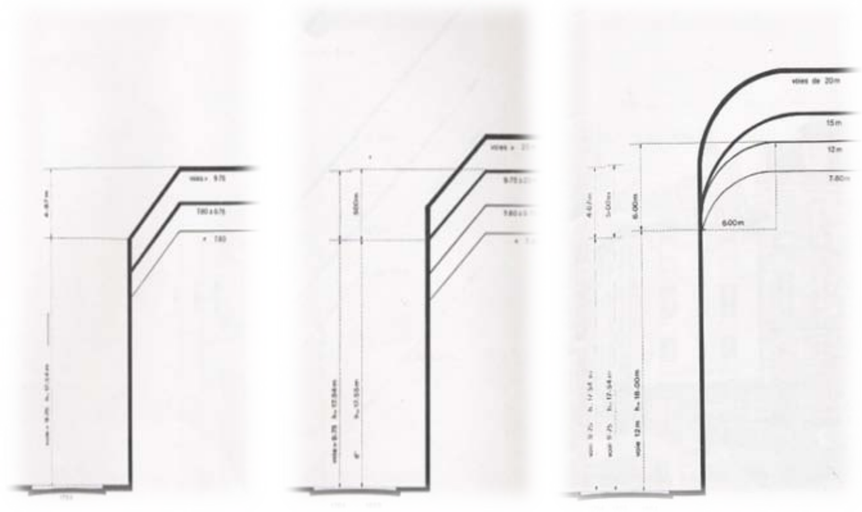
The introduction of roofing regulation height in the system allows us to check the values entered by the user.

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.

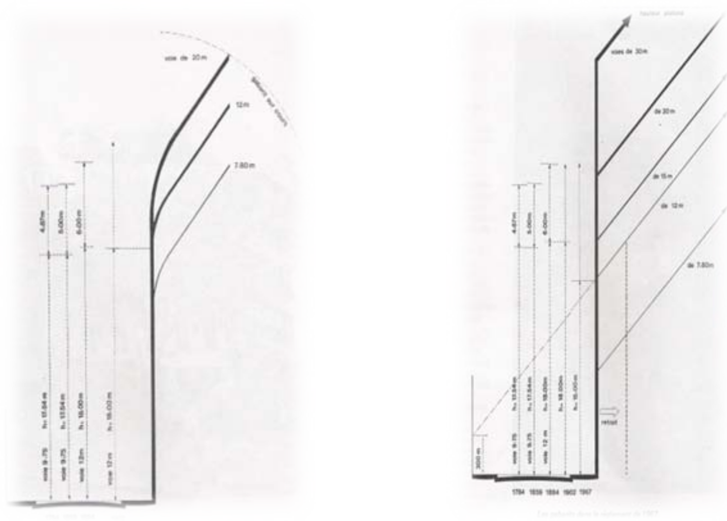
Every type of material leads to a narrow range of values for the slope of the roofing.[15] We can introduce these values into our system as an additional control tool. For example:

- **If** the roofing is constructed in tile **then** $14° \le$ slope $< 60°$
- **If** the roofing is constructed in slate **then** $11°1/3 \le$ slope $< 90°$
- **If** the roofing is constructed in wood **then** $20° \le$ slope $< 48°$

16 Atelier Parisien d'Urbanisme - APUR (1974). ibid



a **b** **c**



d **e**

Figure 2 Evolution of the height of building [after APUR, 1974][16]
a. 1784
b. until 1884
c. until1902
d. until 1967

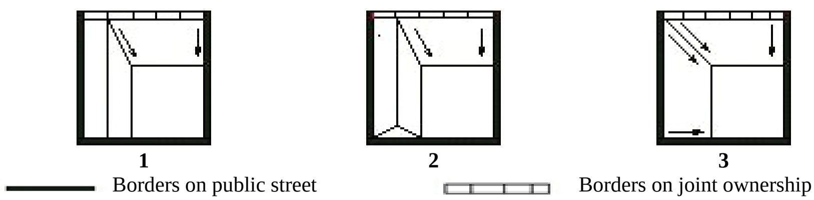


Figure 3 Case of an L shaped building associated with three borders of ownership overlooking Public Street

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 m) with a minimal slope (a) of 45 degrees, the height of the roofing is going to be equal to 3 m for a 20 metres wide (l_2 = 20 m) with the same minimal slope (a) of 45 two-panel roofing and to 6 m for one-panel roofing. But if we consider a building degree the roofing will have 10 m height for two-panel roofing and 20 m height for one-panel roofing (Figure 6).

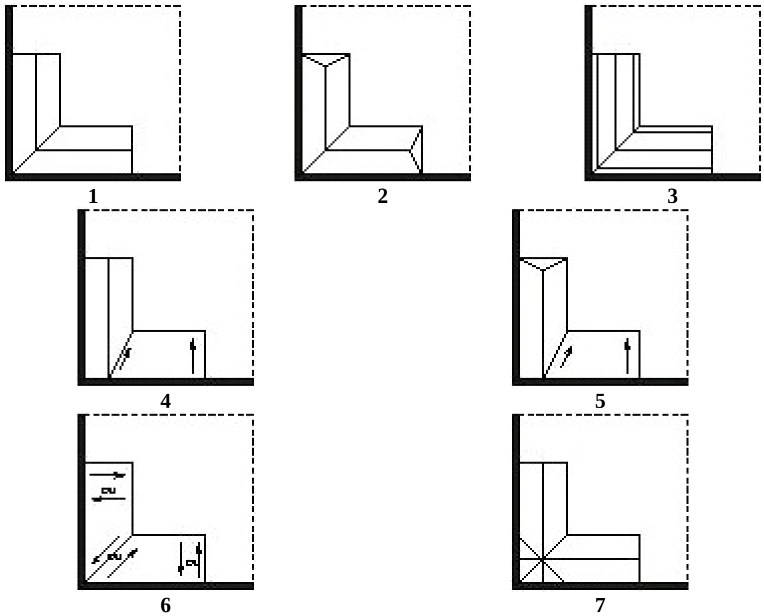


Figure 4 Case of an L shaped building associated with two borders overlooking adjacent Public Street

These two examples show that for the same slope of roofing, we can have heights of different roofing 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.

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 and l (Figures 7, 8). If we take a constant angle for both bodies of building, then we will have roofing with different heights ridgepoles (1 in Figure 7). 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 (2 in Figure 7). 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.

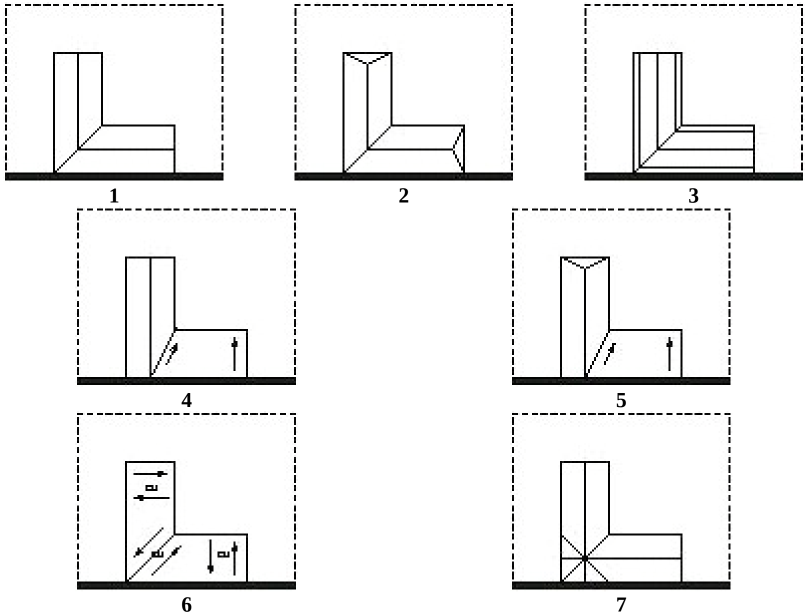


Figure 5 Case of an L shaped building with one border of ownership over-looking Public Street

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.

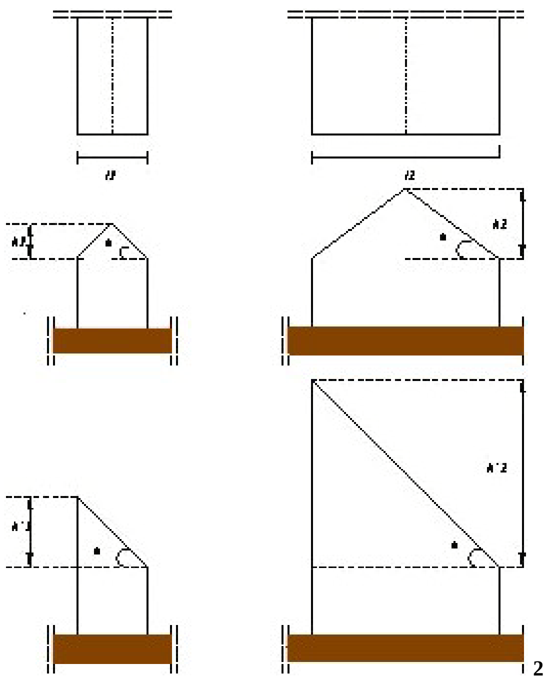


Figure 6 Influence of the roofing range on its height according to its form (roofs with 1 and 2 panels)

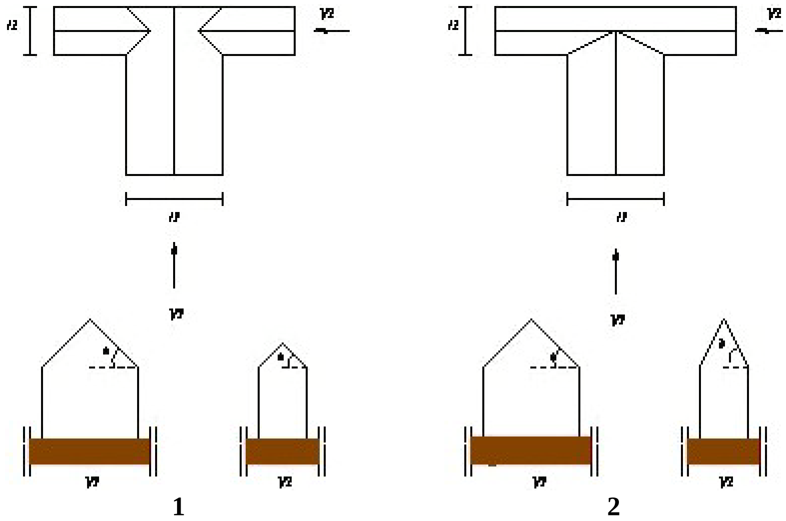


Figure 7 Influence of the breadth of the wings on the roofing: case of a T-shaped roofing:
1. constant angle - discontinuous ridgepole
2. different angles - continuous ridgepole

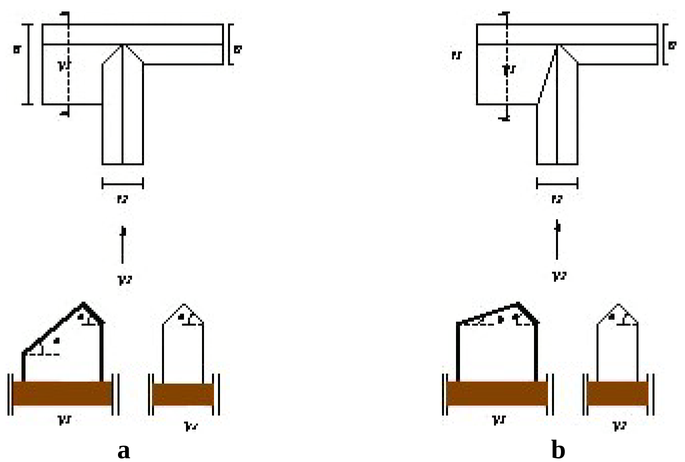


Figure 8 Influence of the breadth of the wings on the roofing: case of T-shaped roofing:
a. Constant angle - discontinuous ridgepole
b. different angles - continuous ridgepole

3 Implementation and Computer Experiments

3.1 The system MEDINA

Our method regarding the three-dimensional reconstruction of the townscape was implemented in a system named MEDINA 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 (Figure 9).

For the reconstruction of the heights, 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 numbers 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 (Figure 10), we call the function which allows the reconstruction of roofs (Figure 11). Among the main steps of this function the execution of the algorithm for determining the shapes of buildings. MEDINA allows the specification of a selection order of the shapes of roofs from different choices (Four-panel roofing, Two-panel roofing, One panel roofing, Mansard roofing). The system allows also the reconstruction of simple roof forms (square, rectangle and some quadrilaterals similar to rectangles), or composed roof forms (L, T and U). It can change at any time parameters of generated roofs (slope angles, shapes, etc.) and the height of buildings.

Figure 9 Cadastral plan of Maxéville

3.2 Experimentation

In this section we present three examples we have tested with MEDINA, namely the Maxéville cadastral plan, the quarter of Boudonville cadastral plan and to the Vandœuvre-lès-Nancy scientific campus quarter cadastral plan.

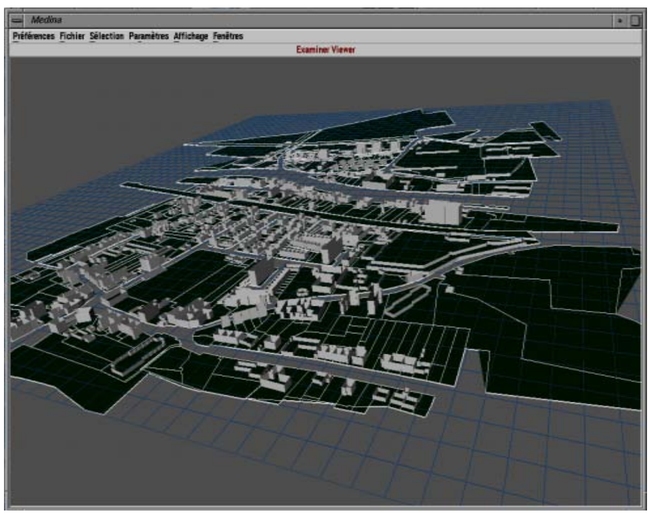


Figure 10 Reconstruction of the heights for Maxéville Cadastral plan

Table 1 Number of recognized polygons by MEDINA for Maxéville Cadastral plan

Polygons type	Number
Square	58
Rectangle	311
L Shaped polygons	86
T Shaped polygons	22
U Shaped polygons	8
Other polygons	1
Non recognized polygons	99
Total	585

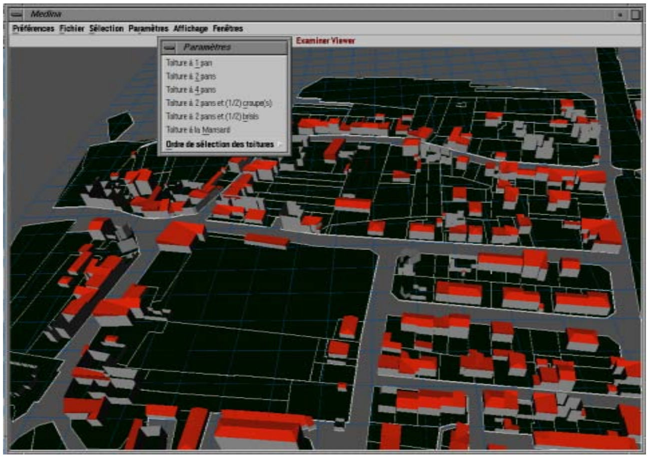


Figure 11 Reconstruction of roofing for Maxéville Cadastral plan

a **b**

Figure 12
a. Maxéville aerial view
b. view generated MEDINA

Table 2 Number of generated roofing by MEDINA for Maxéville Cadastral plan

Roof type	MEDINA	Reality	
		Yes	No
Four-panel roofing	7	4	3
Two-panel roofing	131	120	11
Two-panel roofing and one or two ridges	94	84	10
Two-panel roofing and one or two half ridges	0	0	0
One panel roofing	240	209	31
Mansard roofing	0	0	0
Total	472	417	55

a b

Figure 13
a. Maxéville aerial view
b. view generated MEDINA

Figure 14 Reconstruction of the heights for the plan of Boudonville quarter

Table 3 Number of recognized polygons by MEDINA for the plan of Boudonville quarter

Polygons type	**Number**
Square	41
Rectangle	258
L Shaped polygons	86
T Shaped polygons	20
U Shaped polygons	8
Other polygons	1
Non recognized polygons	200
Total	614

Table 4 Number of generated roofing by MEDINA for the plan of Boudonville quarter

Roof type	**MEDINA**	**Reality**	
		Yes	No
Four-panel roofing	10	8	2
Two-panel roofing	95	89	6
Two-panel roofing and one or two ridges	95	84	11
Two-panel roofing and one or two half ridges	0	0	0
One panel roofing	205	185	20
Mansard roofing	0	0	0
Total	405	366	39

Example of Maxéville cadastral plan

We applied our system to the Maxéville cadastral plan. This allows us to recognize a certain number of polygons which is presented in Table 1 indicating 83% of polygons of the Maxéville cadastral plan are recognized by our system.

The application of our system in Maxéville cadastral plan allows generating automatically the heights of all buildings and 97% of roofs among recognized polygons (Table 2). 88 % of generated roofs correspond to reality.

Figure 12 shows respectively a Maxéville aerial view and a view generated by the system MEDINA. Comparing these two images, we can see that 95% of reconstructed roofs in (b) in Figure 12 correspond to reality. The 5 % that remain represent very limited cases of buildings where the roof forms to return independent choices of roof shapes prevalent in the tissue urban. On the other side, comparing (a) and (b) in Figure 13 allow us to deduce that about 60% of the reconstructed roofs do not correspond to reality. These roofs correspond to large industrial buildings having specific roofs that we have not considered in our study. The process of the heights reconstruction program lasts 1 min 30 sec on a Pentium II PC 300 MHZ frequency. Reconstruction of roofs lasts 50 seconds on a workstation Silicon Graphics 250 MHz frequency.

Example of Boudonville quarter cadastral plan

The second example on which we applied our system was the plan of Boudonville quarter. This allows us to recognize a certain number of polygons which is presented in Table 3.

We can deduce from Table 3 that 70% of polygons regarding to the plan of Boudonville quarter are recognized by our system (Table 4). The application of our system in the plan of Boudonville quarter allows generating automatically the heights of all buildings (Figure 14) and 98% of roofs among recognized polygons (Figure 15). 91 % of generated roofs correspond to reality (Figure 16 and 17). The process of the heights reconstruction program on the example of Boudonville quarter lasts 1 min 37 sec on a Pentium II PC 300 MHZ frequency. Reconstruction of roofs lasts 45 seconds on a workstation Silicon Graphics 250 MHz frequency.

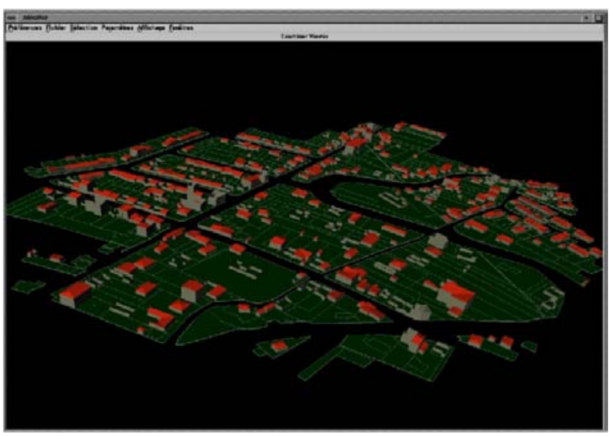


Figure 15 Reconstruction of roofing for the plan of Boudonville quarter

Figure 16 Boudonville quarter aerial view

Figure 17 generated view of Boudonville quarter by MEDINA

Table 5 Number of recognized polygons by MEDINA for the plan of the quarter of the scientific campus in Vandœuvre-lès-Nancy

Polygons type	Number
Square	38
Rectangle	183
L Shaped polygons	88
T Shaped polygons	7
U Shaped polygons	8
Other polygons	0
Non recognized polygons	108
Total	**432**

Table 6 Number of generated roofing by MEDINA for the plan of the quarter of the scientific campus in Vandœuvre-lès-Nancy

Roof type	MEDINA	Reality	
		Yes	No
Four-panel roofing	6	4	2
Two-panel roofing	143	126	17
Two-panel roofing and one or two ridges	64	60	4
Two-panel roofing and one or two half ridges	0	0	0
One panel roofing	106	98	8
Mansard roofing	0	0	0
Total	319	288	31

Figure 18 Reconstruction of the heights for the plan of the quarter of the scientific campus in Vandœuvre-lès-Nancy

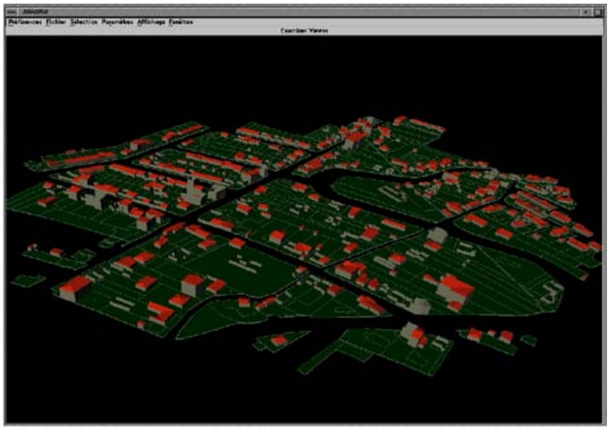


Figure 19 Reconstruction of roofing for the plan of the quarter of the scientific campus in Vandœuvre-lès-Nancy

Figure 20 quarter of the scientific campus in Vandœuvre-lès-Nancy aerial view

Example of the Vandœuvre-lès-Nancy scientific campus quarter

The third example on which we applied our system was the plan of the quarter of the scientific campus in Vandœuvre-lès-Nancy. This allows us to recognize a certain number of polygons which is presented in Table 5. We can deduce from

Table 5 that 75% of polygons regarding to the plan of the quarter of the scientific campus in Vandœuvre-lès-Nancyare recognized by our system.
The application of MEDINA in the plan of the quarter of the scientific campus in Vandœuvre-lès-Nancyallows generating automatically the heights of all buildings (Figure 18) and 98% of roofs among recognized polygons (Figure 19). Ninety percent of generated roofs correspond to reality (Figures 20 and 21).
The process of the heights reconstruction program on the example of the quarter of the scientific campus in Vandœuvre-lès-Nancy lasts 1 min 32 sec on a Pentium II PC 300 MHZ frequency. Reconstruction of roofs lasts 37 seconds on a workstation Silicon Graphics 250 MHz frequency.

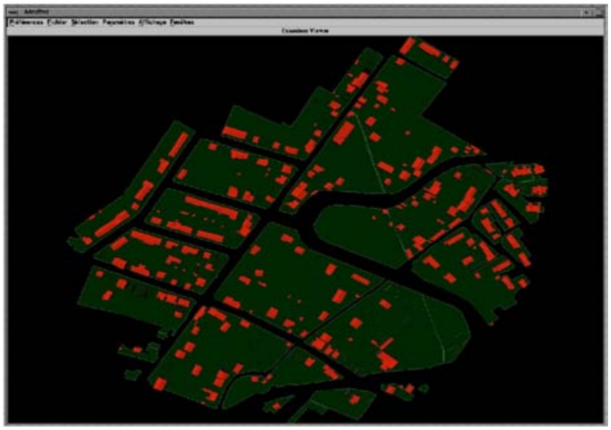


Figure 21 generated of the scientific campus in Vandœuvre-lès-Nancy by MEDINA

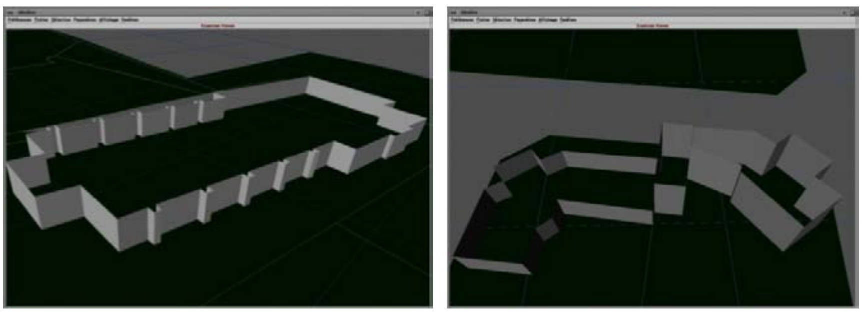


Figure 22 Examples of non-allowed polygons

3.3 Discussion

The application of our system to the Maxéville cadastral plan, to the quarter of Boudonville cadastral plan and to the Vandœuvre-lès-Nancy scientific campus quarter cadastral plan, allowed us to recognize respectively 83%, 70% and 75% of polygons. Our system 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 (Figure 22). Let us mention that the percentage of the generated roofs which correspond to the reality varies between 88% and 91%.
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.

Our system requires minimal interaction with the user. Indeed, the user can intervene early on the program to decompose the cadastral plan in one or more urban fabrics and introduce to each one of them the heights of the ground floor and the upper floors. He can also specify a selection order of roofs forms. At the end of program execution, the user can intervene, if necessary, to modify the parameters of generated roofs and the height of buildings. Finally, the intervention of the user is essential for the reconstruction of special cases of roofs that are not currently treated by the system.

4 Conclusions

As opposed to the majority of technical methods allowing an exact and precise 3D reconstruction of buildings and requiring expensive resources and investments (aerial remote sensing…), we succeeded to build a 3D plausible volumetric urban environment at low cost, by using available documents and a database of knowledge issued from urban legislation and technical rules.

We think that the implemented method should help the designers, town planners and architects, by giving them the possibility to obtain 3D urban fabrics starting from simple 2D data. Our system can also be of great interest to educational establishments and small professional structures as well, which cannot afford expensive charges of accurate and expensive methods. 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.

The main objective of our work in the medium and short term is to get through a system which limits as much as possible repetitive interventions of user with maximum automation for the three-dimensional reconstruction process of urban fabrics. Among the points we plan to consider, we can cite the following:

- Experiment on other examples: We tested our system on three examples of the city of Nancy and its suburbs. It would be interesting to study other examples of different cities. These experiments will help us to identify the most common forms of buildings and roofs that we have not considered and it is essential to proceed to their reconstruction.
- Introduction of other types of polygons: In this research, we treated the most frequent cases of polygons as simple polygons (square, rectangle and some quadrilaterals treated as rectangles by introducing an angle tolerance) and composed forms of polygons (L, T and U forms) with definite proportions reports between different segments.

If the application of our system on the cadastral plan of Maxéville, the cadastral plan of Boudonville quarter and the cadastral plan of scientific campus of Vandoeuvre has generated automatically the majority of the roofs, there are still some percentage that represents simple polygons types such as the tower or polygonal apse and more complex forms. We can cite for instance, public or industrial buildings whose special dimensions give the possibility of original roof configurations. Therefore, we plan to study the adaptation of our techniques to the recognition of these types of polygons and the modelling of their roofs.

- Introduction of other types of roofing: In this work we have considered roofs with continuous ridgepole. Our three-dimensional reconstruction technique should be adaptable to the treatment of roofs with discontinuous ridgepole.

- Use other types of documents: Our system uses digitized cadastral plans. These documents do not contain information on building roofing. That's why the user must intervene early in the program to introduce a choice order for the selection of roofing (a pan, two pans, etc). It is interesting to consider other types of documents from Urban Information Systems (UIS). These documents could help us to distinguish automatically different urban fabrics types and associate to each one of them a choice order for roofing selection.

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