Modelling specificities of a physical town scale model.

C. Chevrier, K. Jacquot and J.P. Perrin
CRAI-FRE 3315, National Superior School of Architecture of Nancy, FRANCE.

Abstract

In this paper, we present a new method for the 3D reconstruction of town scale models. They are special objects because of the very small size of the buildings and of the other details in comparison to their corresponding one-by-one scale objects. Furthermore time hasn't spared the delicate materials like wood, paper or silk covering our scale model. Our method was first tested on the scale model of Toul (France) which contains both built-up and countryside environments. The virtual 3D model has to be light but reliable because one of the applications will be on the web. Thanks to the skeletons of the roofs manually extracted from the pictures with Photomodeler, we automatically create buildings. Automatic and manual adjustments allow us to correct geometrical deformities and to add parametrical objects like vegetation, openings, chimneys, belt courses, etc.

Keywords: 3D modelling, web application, cultural heritage, photogrammetry, lasergrammetry, scale model.

1 Introduction

To preserve and promote our cultural heritage, computer digitization has been widely used for years: scientific and architectural studies for surveying the evolution of the building deformations, virtual visits for a better understanding of a monument or a city, illumination simulation projects, better access to delicate heritage objects for researchers as well as for the general public.

Even though sensors and techniques are widespread, the variety of artifacts is so huge that some objects may not be digitized thanks to these well-tried methods. Contrary to statues, buildings or archaeological sites, less work has been conducted in digitization of scale models. The size and scale are components to be taken into account when scale models are the aim of a project.

The Museum of Plans-Reliefs at Les Invalides in Paris and the SRI (historical research center) of Lorraine have given us the task of creating a virtual 3D object of a physical scale model dating from the 19th century: the scale model of the town of Toul in France (see Figure 1).

There are about one hundred scale models of French towns, all at the scale of 1:600. They were made from the 17th to the 19th century by the army to visualize fortification projects or to elaborate war strategies. Built in the 1840s and modified in the 1860s, the Toul model was made a few years before the end of the fortification systems. Its size is about 39 m2 and it is composed of 20 pieces (called tables). The biggest contains the town (2.31m x 2.23m). The other tables contain hamlets and countryside.

For 2010, we were asked to model a part of the town table (see Figure 2) and a countryside table (1.50m x 2.50m) (see Figure 3). This first test must enable us to elaborate an "as automatic as possible" method and determine if it is conceivable to digitize the other tables of the scale model of Toul and also other scale models of the collection.

The need to digitize the scale model of Toul is multiple. By creating a 3D model, we preserve a witness of the architectural and urbanism evolution. As we will see in part 3, the model of Toul is in a bad state due to its age and to the conditions of its conservation. There is also the will to provide a greater access to this delicate model for the general public and for historical researchers because most of the scale models are stocked in boxes where nobody can see them. Only 26 are currently exhibited at Les Invalides Museum behind glass to avoid dust deposit.

Interactive terminals for the museum and web applications are the best media to solve the lack of visibility of the smallest town parts of the scale models. They will also allow navigation into the virtual model which means a greater access to further information via hyperlinks.

Apart from the scale model, we also have at our disposal 2D plans (roof plans and elevations plans that have been used by the original model makers). Unfortunately, we were not able to use this precious information because of the inconsistencies between them and the scale model. However, these plans helped us to get our bearings in the great amount of buildings (more than 4 000 in the town).

The project of digitization of the scale model of Toul is at the mid-point of two research fields: photogrammetry and lasergrammetry on the one hand and 3D parametric modelling of architectural elements on the other hand. Complex architectural elements are still impossible to obtain without human handling but it is likely that some steps can be accomplished automatically with a minimal user help.

In this paper, we present the project starting from the 3D modelling of the buildings and vegetation to the web application we have developed. After a presentation of related works (part 2), part 3 explains the specificity of a scale model compared to a town. Then the method we have conceived and developed for an "as automatic as possible" reconstruction of the building is explained in part 4; this part has been explained in detail in (Chevrier, 2010). Part 5 deals with the modelling of vegetation. The web application is exposed in part 6. Finally, we conclude and present future work in part 7.

Figure 1: Picture of the scale model of Toul

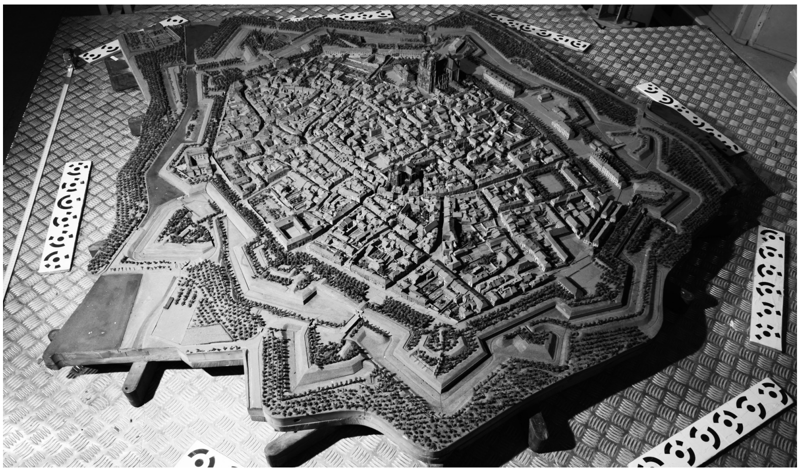


Figure 2: Picture of the city table of the scale model of Toul (France).

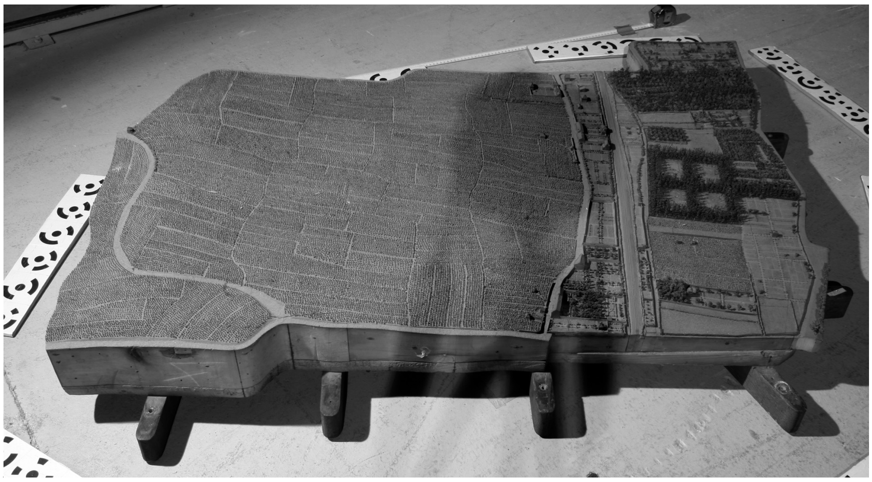


Figure 3: Countryside table (1.5 x 2.5m). Vegetation is widespread and of various kinds. The biggest part is planted with vine stocks.

2 Related works

Methods for the creation of digital models from physical scale models can be classified in two kinds: manual accurate modelling with CAD tools and many people or plausible automatic modelling with procedural methods. We haven't yet found any automatic and accurate modelling of town scale models.

The Langweil model of Prague was made in 1827 (http://www.langweil.cz/index_en.php). It is half as big as the scale model of Toul and its 52 tables (160 x 100 cm for the biggest) allow a better access to the different parts of the model. The scale is bigger: 1:480 and it is also in much better shape. Textures are more elaborate but the volumetry is basic with paint windows for instance. More than two hundred people skilled in robotics, programming, modelling and photographing were involved and a partnership with Autodesk was made to take advantage of their experience. A special robot was created to photograph each of the 52 parts of the model thanks to cameras containing macro-optics, highly precise CCD sensor, etc. However the 3D modelling of the buildings was realized manually. ImageModeler software was modified to meet the issues of the building reconstructions whereas photogrammetric treatments of points cloud from 3D scanners ensure the creation of the digital terrain model (DTM) (Sedlacek, 2009). Two kinds of applications were carried out with the resulting model. The first one allows scholars to examine the digitized model, without having to go to museums, reducing the risks of spoiling. The second kind of applications is CDs designed for the public with interactive virtual guides or adventure games for children.

Carried out by several university laboratories, the Rome reborn project aims at illustrating the urban development of ancient Rome from 1000 BC to 500 AD thanks to the Plastico di Roma antica scale model. Because of the size of the model (280m2), the researchers have chosen to digitize it by means of two lasers: a 3D laser radar (time of flight laser) because of the large dimensions of the physical model and a triangulation laser for the digitization of detailed parts. (Guidi, 2005; Fuchs, 2006). For the 5% of well documented buildings (Circus Maximus, Colosseum, etc.), the 3D reconstruction is made thanks to Autodesk 3DS or Multigen Creator. What remains, about 10 000 buildings, is modelled with CityEngine, a procedural tool that uses the volumetric data from the 3D scanner to create credible buildings but not necessarily correct (Dylla, 2009). The model is thus a representation of the state of our knowledge that can be easily updated to reflect new discoveries. The medium used to diffuse this model is the popular Google Earth application.

Few others projects were carried out. For instance, there is the project of 3D reconstruction of the scale model of Beijing (Zhu, 2009). The whole model was made in the 1950s and assembled using 94 parts. The 1:1000 model covers an area of 75 m2. The digitization is carried out thanks to structured light photogrammetry and extraction algorithms. Few tests were done and no application is known. See (Chevrier, 2010) for related work in photogrammetry and lasergrammetry methods.

3 Specificities of a scale model compared to a town

The aim of the project is to get an “as accurate as possible” virtual 3D model of the scale model of Toul in France. The scale model is made of delicate material like wood, paper, and silk. Compared to a 3D modelling of a real size town, the plan-relief has its own constraints due to its scale, size and age:

- Due to the very small scale of the physical model (1:600), the buildings are a few centimetres high, openings are often one millimetre wide, streets are about 1 to 2 cm wide with some alleys less that 5 mm wide. The physical scale model is not a perfect representation of the reality. Such a small size is not compatible with accuracy. Numerous architectural inconsistencies were made during the physical creation of the scale model in 1840. Any mistake or imprecision is instantly obvious when you are in the virtual 3D model without scale.

- There is just the essential on the scale model: no perturbing objects in the streets (trees, urban furniture).

- Digitization has to be carried out without contact, purely on optical principles using non-contact, non-destructive sensors.

- Because of the density, some areas of the model are not easily accessible, many houses cannot be well documented.

- Moving the model without a skilled team to access some areas is impossible because of the size, the weight and the fragility of the model.

- The scale model is in a bad state: papers are unstuck or missing, a lot of dust is on the model, and slopes are skew surfaces (see Figure 4).

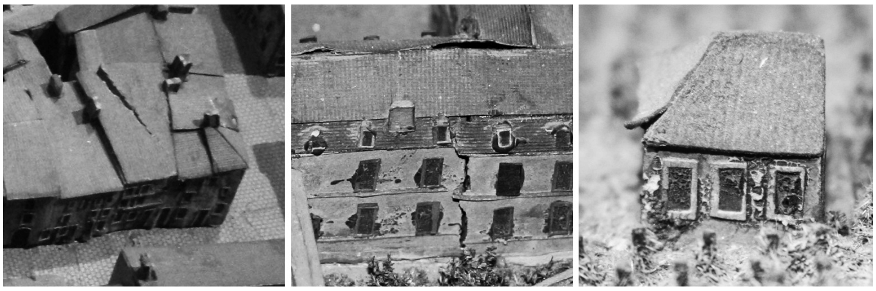


Figure 4: damage is widespread: unstuck papers, lots of dust, skew surfaces due to deformation.

4 The method

Because of the specificities of the project, the range of tools suitable for digitization becomes restricted. Moreover, it is necessary to combine several technologies like image-based processes (Photomodeler http://www.photomodeler.com) and range-based modelling (Geomagic http://www.geomagic.com) to achieve the digitization of the scale model. The key to this work is to merge these technologies where they are best suited. Figure 5 shows the principles of the method.

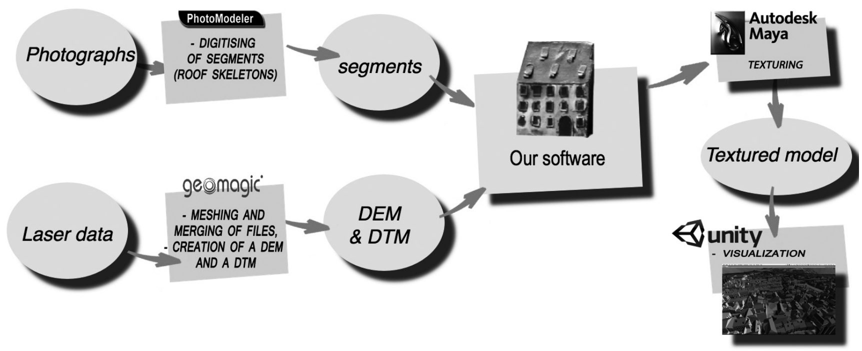


Figure 5: Principles of the method

The scanned ground geometry is treated with Geomagic to create the DTM (Digital Terrain model) that will be used as the ground model for the countryside.

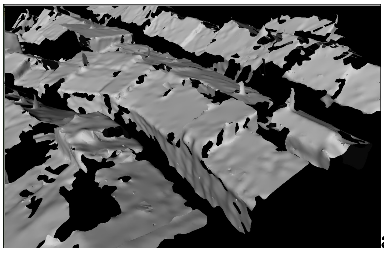
PhotoModeler, a photogrammetric software, lets us recover the roof edges of the buildings and low walls. They are automatically reconstructed taking into account several parameters and constraints like the roof slope planarity.

Maya software (http://usa.autodesk.com) is used to texture the model and Unity software (http://unity3D.com) is used to create the application.

5 3D modelling of the terrain

We were not allowed to touch the model. After much discussion we were authorized to lay several sewing threads in surrounding streets. In the first experimentation, the use of the Handyscan scanner (http://www.creaform3d.com/en/default.aspx) allowed us to have a roughly 3D model of the city where houses looked like heaps of sand (resolution of 2 mm). To obtain usable laser point clouds, we had to increase the precision of the tool which delayed the operation (half a day for a 30cm x 30cm box) but makes easier the positioning of the 3D buildings on the point cloud. Nevertheless, we encountered difficulties in accessing the inner blocks. Furthermore, the scale model of the town part is just one big object (2.31 x 2.23m).

Several tries have were made (see Figure 6) with various laser precisions: 0.3mm and 0.5mm. At 0.3 mm, results are accurate but the time taken to scan is too long. We could not spend two months on the scan. A 0.5 mm precision turned out to be a good compromise between quality and the time spent scanning: 6 days for the town part.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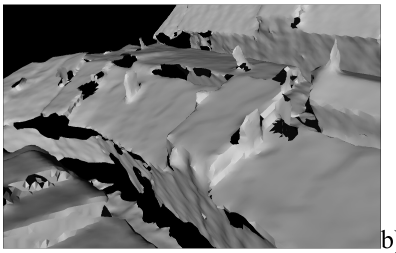
b)

Figure 6: Scanned parts realized with a precision of 0.3mm (part a) and of 0.5mm (part b). A resolution of 0.5 mm is a good compromise between time spent and quality.

From the DEM (Digital Elevation Model) we created the DTM with Geomagic (http://www.geomagic.com): buildings and vegetation were removed, holes were filled. The DTM was used as a support for the setting up of buildings and vegetation. The country part of the DTM was textured and used as the virtual terrain for the 3D visualization.

For the city part, a Delaunay triangulation between the houses' ground polygons was then carried out thanks to Triangle software (http://www.cs.cmu.edu/~quake/triangle.html) in order to replace the DTM corresponding to the roads with a lighter model so that the web navigation remains fluid.

6 3D modelling of the buildings

Three main steps must be completed to obtain the 3D model of the buildings. PhotoModeler, a photogrammetric software, lets us recover buildings' roof edges and low walls (part 6.1). Then automatic corrections of the segments are applied and the buildings are modelled (part 6.2). Finally, to have an accurate model, many objects are added to the buildings like chimneys and openings (part 6.3).

6.1 Segments created with PhotoModeler

As mentioned before, the size of the town parts and dust deposit are constraints that extend the time spent in taking photos. The rear of the buildings can be very dense especially in the centre of the model where the city blocks are hard to reach. Thus photos do not show every part.

The first step of the method involves the manual digitizing of segments forming the roof skeletons (Figure 7). To create a 3D point, we have to locate it in two photos but there is nothing to prevent the creation of this point on other photo-couples. The treating of these extra segments is a waste of time. Moreover, the geometry created by PhotoModeler has no geometrical properties held by the buildings like parallelism, planarity or horizontality. Like every photogrammetric tool, bad orientations or inaccurate points contribute to a lack of quality but in our case, the model is so damaged that everything is irregular.

We work city block by city block with oblique pictures. The level of accuracy of the photometric data is around seven pixels for all the city-blocks. This high level is due to imprecise points we had to position although they were not seen in any picture or to points in blurred parts of the pictures. This level of accuracy corresponds to approximately half a millimetre.

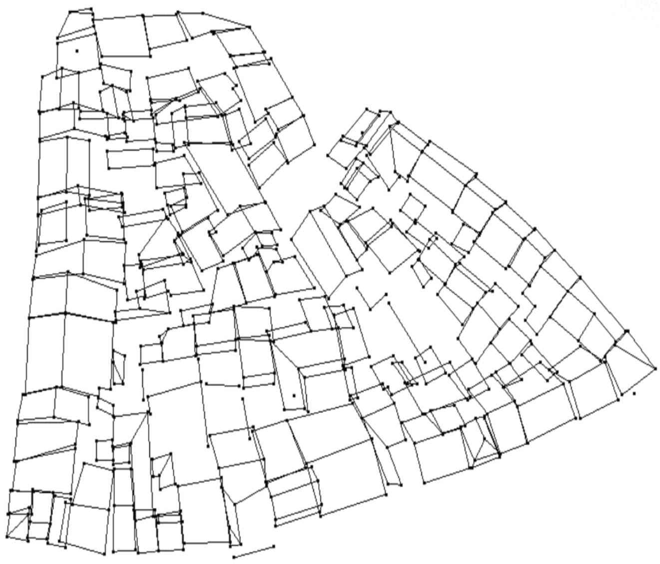

Figure 7: The roof skeletons of a city block before geometrical corrections

6.2 Modelling the roofs and walls

From this point, we use our own software to carry out the following processes. For more detail of this part, see (Chevrier, 2010). The segments of a city block are positioned automatically in the DEM with the help of three selected points in the DTM and the three corresponding points in the PhotoModeler data. This allows us to scale and orientate the segments. Manual refinements are possible if necessary.

Then automatic treatments modify the geometry of the segments to correct parallelism or remove excess points and segments to make up for the PhotoModeler's geometric imprecisions (every face is a skew surface, nothing is parallel and roofs can penetrate each other).

We developed algorithms able to identify every kind of edge and slope of a roof. Thus, roofs are modelled with parameters and constraints like planarity of the roof slopes, horizontality of the ridge. Overhangs are modelled and some values are automatically computed from the relationship between two neighbouring roofs. Finally the walls of the building are created by projection of the roof points on the ground (DTM).

6.3 User interface for the refinement and the adding of openings

Finally, a user interface allows us to modify some parameters, apply constraints or change values. For each edge, we can play with the type of segment and its overhang value. Roof thickness, roof planarity, horizontal roofing, parallel roof edges or ridges are the parameters for roofs. However, we allow the possibility to modify the position of a point in case the constraints fail to treat that point.

At this stage and to complete the model, we can add elements. Some of them are attached to the walls (openings or belt courses) while others are attached to the roof (chimneys or dormer windows). Some problems occur during the sizing of these objects. While the chimneys may be easily located and sized thanks to the superposition of the MNE, the openings are a real issue. They are realised on the physical model with stuck papers, so they do not appear in the laser data. We have to rely on photographs. Because we cannot have orthographic views of the facades, the heights are crushed and openings tend to be shorter than they really are.

The positioning of an opening is automatically made on the chosen facade with the parameter values given by the user. The user estimates the parameter values with the help of the pictures. This step relies on a personal appreciation. Various persons do not produce the same results. This task is time consuming and must be improved and automated in the future.

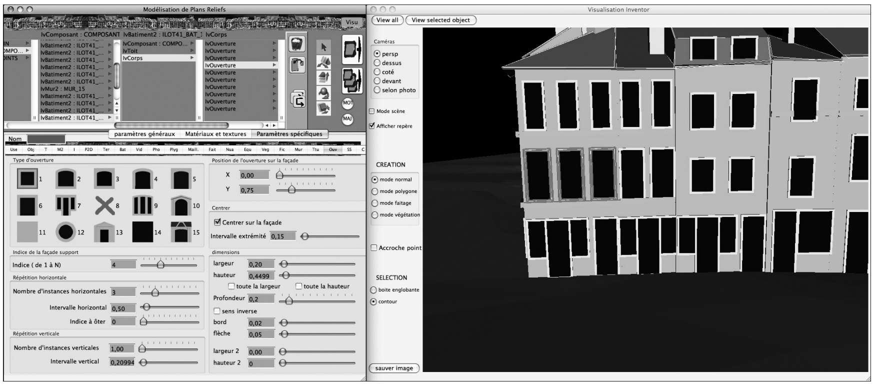

Figure 8: The interface for the positioning and the sizing of the openings.

7 3D modelling of the vegetation

Vegetation on the physical scale model is mainly made of copper wire and pieces of silk. We have identified approximately ten main kinds from salads or cabbages in kitchen gardens to high trees like beech trees in forests. Some written documents tell us what kind of trees was used in some streets or squares and how vegetation was made.

Each kind of vegetation has been modelled directly with Unity sofware. We have developed an application to plant vegetation on the DTM. On the DTM textured with a picture of the table, the user locates some points and indicates which kind of vegetation it is. In our software we only materialized the location and the kind of vegetation with various colours and sizes. It is only in the Unity application that the 3D vegetation models are used.

Figure 9: We plant some vegetation on the DTM of the country table.

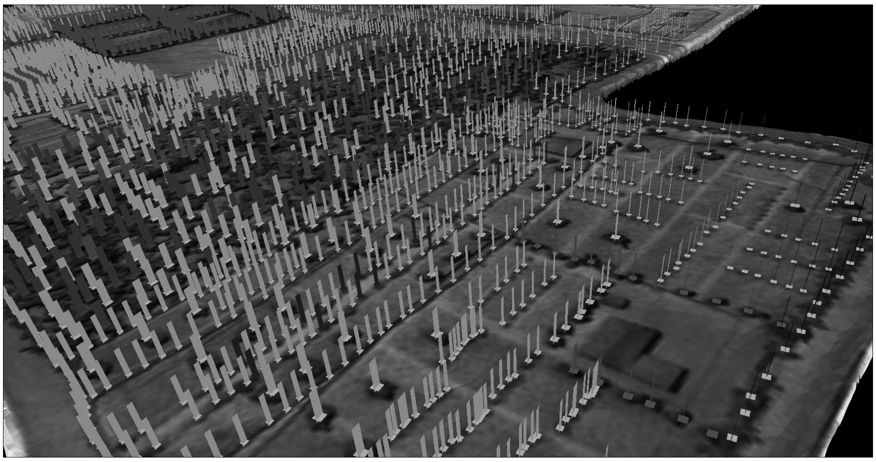

Figure 10: Simplified representation of vegetation for the creation step.

8 Web application

In order to have a fluent move in a heavy database via the WWW, one must choose a powerful 3D viewer. We have chosen Unity software, which is a game development tool that can be used in the web. It is appropriate to handle heavy 3D models. Our aim is not to create a game but the potentiality of these kinds of software is great. Via the web, a free Unity player is used.

8.1 Unity

Unity has a graphical user interface for the creation and handling of 3D objects. We can also predefine some paths of navigation or leave the user free to navigate by himself in the 3D model. Unity handles the collisions on the contrary of VRML viewers for example. It allows also writing some scripts to create one's own specificities.

About 8400 vegetation objects (without the 30000 vine stocks) are present in the two tables. The number of buildings is close to 900. We estimate the total number of buildings to be up to 4 000 for the entire scale model. It is difficult to assess the total amount of vegetation but we know that there are 871000 vine stocks according to the written documents of that period.

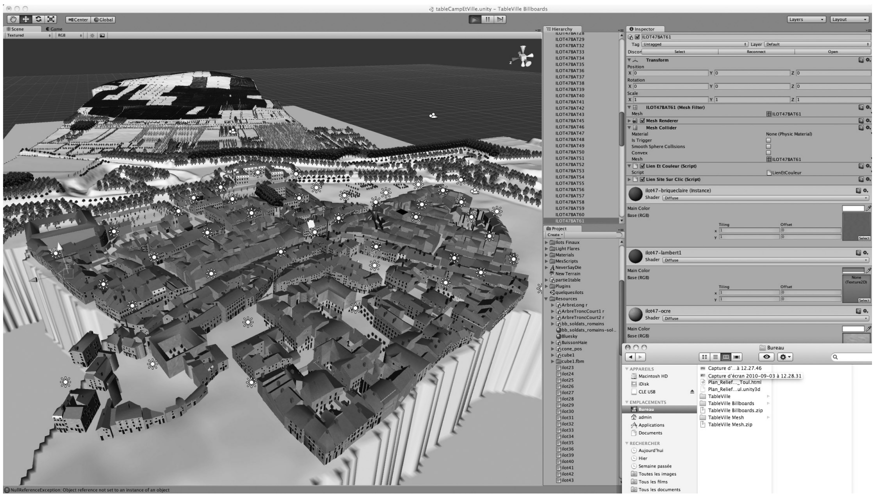

Figure 11: The interface of Unity and the final 3D model for vegetation.

8.2 Navigation and access to other documents

Each building and road can be potentially linked to a web address for more information. To avoid game compilation each time there is a change, we use text files in which is written a correspondence between an element and a web address. When the persons responsible (let's call them the game masters) of the files have a change to make, they only make changes in the files and do not touch the Unity game anymore. The web address for a building gives information on that building or on the city block. It is most of the time a request in a database containing documents (images, pictures, sketches, texts, etc). There is another file for the name that must appear as information when the mouse is over an element. For instance, the building named "BLCOK35HOUSE24", computer name automatically given during the creation process, must display: "Saint-Gengoult Church".

Figure 12: Part of the city. Objects that appear in red when the mouse is over are clickable to access specific information about it.

Figure 13: the country table and its vegetation.

9 Conclusion and future work

In this paper we have exposed the methods and software we have developed for the reconstruction of a scale model of a town made of wood and paper: we automatically create the buildings from segments manually extracted from the pictures. We have also presented the web application we have created to allow researchers and the public to navigate in the model.

One can access the 3D model on: http://www.crai.archi.fr/Toul/modele.html

Till now, only a part of the town has been modelled (approximately 1/14). The data files for that part is 23 Megabytes. Tests made via the web with various connections types and computers were satisfactory. However it will be a challenge to display the 3D virtual model of the entire scale model of Toul on the web.

This project was a one-year contract financed by the French Ministry of Culture. In the future we will try to find financial support to model the other parts of the town and the other countryside tables. We will also work on the textures to improve the shading of the buildings. As far as the automatic process is concerned, several important points could be improved or tested:

- Trying our methods on existing towns (aerial photographs and laser data).

- Improving the step of acquiring the segments of each roof. This step is currently carried out manually with PhotoModeler software. For this we plan to collaborate with researchers in computer vision and photogrammetry.

- Implementing automatic techniques for the positioning of textures and openings.

- Making use of the DTE to adjust the roof geometry with an automatic detection of planes as in (Tarsha-Kurdi, 2007) for example.

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