

ACQUISITION, MODELING AND GIS INTEGRATION OF A 3D MODEL OF THE FRAME OF XVITH CENTURY HISTORIC BUILDING

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ABSTRACT:

The aim of the project described in this paper was to define a three level frame survey mode of an old building: the so called "Andlau's Seigneurie", Alsace, France. Two different techniques were compared for the data acquisition: 3D TLS and point extraction and classical surveying with a total station. According to them, different modeling processes were also defined for the creation of a 3D virtual model of the frame. The data were structured and the model was created to be used for an interactive animation in a museum. The different steps of the project can be described as follow: 1/ definition of a identification system of the frame beams and understanding of the frame structure, 2/ comparison and adaptation of two data acquisition methods to the particular context, 3/ design of a GIS model including complementary information like photographs, size, specific attributes. The final modeled frame was then integrated in the 3D model of the entire building.

RESUME :

Le but principal du projet décrit dans cet article était la définition d'un mode de relevé et de modélisation de la charpente d'un bâtiment historique : "la Seigneurie d'Andlau", Alsace, France. Deux techniques différentes ont été utilisées et comparées pour l'acquisition des données : le scanner 3D terrestre et l'extraction de nuages de points ainsi que la mesure classique à l'aide d'une station totale. Associés à ces méthodes de relevé, des processus de modélisation spécifiques ont été définis pour la création de modèle 3D virtuels de la charpente. Les données ont été structurées et le modèle créé pour une utilisation sous forme d'animation interactive dans un musée. Les différentes étapes du projet peuvent être décrites comme suit : 1/ définition et compréhension de la structure de la charpente et adaptation d'une méthode de numérotation des différentes poutres, 2/ comparaison et adaptation des deux méthodes d'acquisition au contexte particulier, 3/ implantation dans un modèle de SIG incluant des informations complémentaires comme des photographies, des dimensions, des attributs spécifiques. Le modèle final de la charpente a été intégré dans un modèle 3D du bâtiment complet.

1. INTRODUCTION

The aim of the project described in this paper was to define a three level frame survey mode of an old building: the so called "Andlau's Seigneurie". The "Seigneurie" was built in 1582 by a son of Frédéric d'Andlau. The lords of Andlau possessed several residences in this region. It was a mansion occupied by the lords of Andlau between the XVIth century and the French Revolution in 1789. This ancient mansion retranscribes the fashionable architecture at the end of the XVIth century (Renaissance style). In 1934, the facades of the main building were registered on the additional inventory of Historic monuments. In 2005, the commune of Andlau, Alsace, France became the owner. Two different techniques were compared for the data acquisition: 3D TLS and point extraction and classical surveying with a total station. According to them, different modeling processes were also defined for the creation of a 3D virtual model of the frame. The data was structured and the model was created to be used for an interactive animation in a museum. The different steps of the project can be described as follow: 1/ definition of a identification system of the frame beams and understanding of the frame structure, 2/ comparison and adaptation of two data acquisition methods to the particular context, 3/ design of a GIS model including complementary information like photographs, size, specific attributes. The final

modeled frame was then integrated in the 3D model of the entire building.

1.1 Initial tasks

The Figure 1, shows an overview and the environment of the building.



Figure 1. The "Andlau's Seigneurie"

1.1.1 Reference system

At first the three different levels of the frame had to be connected and referenced in a same coordinate system. An inside-outside survey was realized all around the building and through the windows. Thus all the levels contained a sufficient number of reference points known in x, y and z coordinates. The estimated accuracy of the reference system was evaluated to $\pm 0,7$ cm in x, y position and $\pm 0,5$ cm in altitude. The accuracy of the reference system was very important because it has defined the precision of the registration of the point clouds while data acquisition.

1.1.2 Structure of the frame

In a second step, the structure of the frame was analyzed to define a comprehensive theoretical model of it. This model was used to fix a numbering system of the frame beams to facilitate the further modeling process and to prepare the structure for the integration in the future 3D GIS. The identification model is composed of five elements : it is based on floor number (from 1 to 4, side of location (1 for east side, 2 for west side, 3 for interior part), location module (from 0 to 9 on east part, from 1 to 9 on west part, type of beam [letter code], number (ordered in each module). For instance, the beam number 216RA1 (Figure 2) corresponds to the beam located in the 2nd floor of the timber work, on the east side, in the 6th module, RA for rafter as beam type, first rafter in the module.

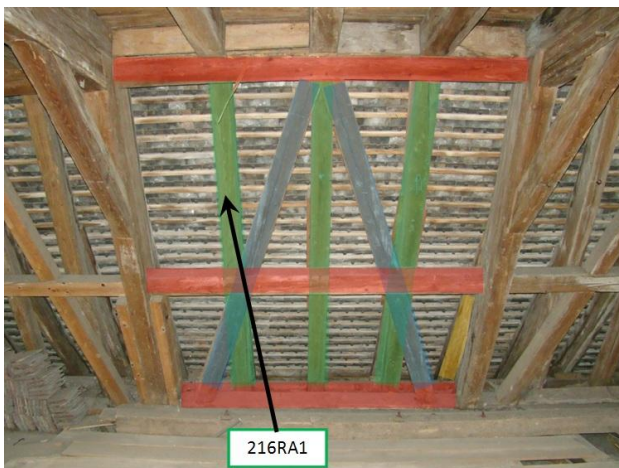


Figure 2. The structure of the timber work, identification system

This identification system allowed also the documentation of each beam with complementary information like photographs for detailed parts of a particular beam, technical documents, etc.

2. DATA ACQUISITION

Two different methods for data acquisition has been used. For the first method the "Trimble GX" 3D TLS was used. To complete the survey and compare another data acquisition method, the "Leica TS02" Total Station was also used.

2.1 3D TLS data acquisition

The "Trimble GX" 3D TLS is an advanced surveying and spatial imaging sensor that uses high speed laser and video to capture coordinates and image data. The scanner collects millions of points for photo-realistic resolution, but only a

number of points were necessary for this type of project. For each of the three levels, about 9 scanner stations were used. Each scanner station was directly registered on the field by using the upper described reference system. The registered point clouds were then transferred to "Trimble Realworks" software and finally segmented according to the corresponding processing method described in next section. The resolution of data acquisition was 5 mm at 5 m.

Having experimented this method, we can extract the following advantages from it: i/ the survey process is fast, and the presence of an operator is not compulsory, because the 3D scanner works alone, ii/ 3D Scanner supplies a good and helpful texture, iii/ the first result is realistic, iv/ lack of luminosity is not a matter, v/ the design obtained is detailed with a lot of information (texture, color, etc.).

Drawbacks of this method were the following: i/ all points were measured, thus more information than necessary were collected, ii/ with a great number of points, processed files were bigger and heavier, segmentation, point selection and extraction were necessary tasks, iii/ scan was limited in vertical angle to 60 degrees, so it was impossible to scan the last floor, because this floor was very high and narrow, iv/ importing and drawing on CAD software was taking a long time. The Figure 3 shows a partial view of the different point clouds acquired for the first, second and some fragment of the third framework level.

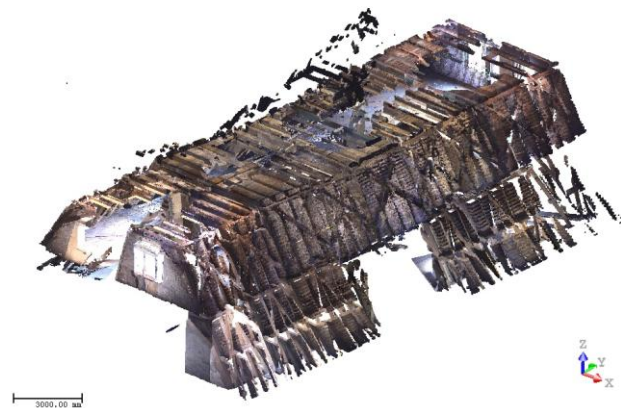


Figure 3. Merged rough point clouds at different levels of the timber work.

2.2 Total station data acquisition

To complete the survey and compare with another data acquisition method, the "Leica TS02" Total Station was also used. This Total Station has permitted to do standard measurement tasks, designed especially for mid-to-low accuracy applications. It works with a laser pointer and a distance measurement system without reflector. Contrary to the TLS data acquisition, the operator must pinpoint every point of interest, that is to say each end of beam. The method gave no complementary information on the sides of beams, but only on their overall dimensions (length, width) and position.

This second method has following advantages: i/ Only selected points were measured, ii/ there were less points to take in account, then the processed files were smaller, iii/ calculating xyz-coordinates of points was easy, iv/ drawing on CAD system was easy: just connect the dots to draw the beams, v/ drawing time was shorter (about two hours per module).

But, on the other side, this method has some disadvantages: i/ the survey process was longer (about one hour for each module) and required an operator who had to pinpoint every point, ii/

attics were dark and measure the beams was not always as easy as estimated, iii/ the design obtained were sketchy and a lot of information were missing (Figure 4), iv/ only measured points are registered and in case of forgetting, it is necessary to return to make a complement.

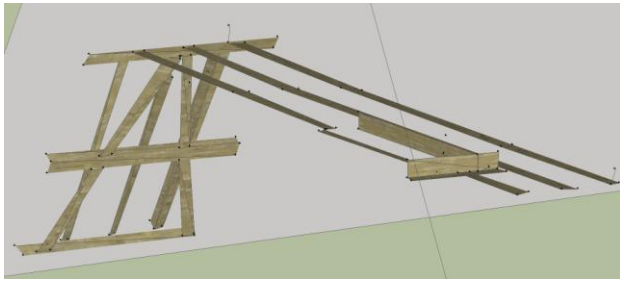


Figure 4. Total station data acquisition and poor modeling with “Google Sketchup” software.

3. PROCESSING METHODS OF THE POINT CLOUDS

After data acquisition with a 3D TLS, we obtained big point clouds from which the challenge was to extract only necessary datasets to model the timber-work with a the best accuracy as possible. The theoretical model gave the global structure of the frame. Such a theoretical model be designed on a specialized software, like “Autodesk Revit Structure”.

The different following section describes 8 different approaches tested for the modeling of the historic timber-work.

For each method the preprocessing consisted in a segmentation of the point cloud into beam objects. These segmentations were manually operated on the “Trimble Realworks” software. The result of the segmentation a partially objects with maximum data for three of four faces.

The methods compared were the following:

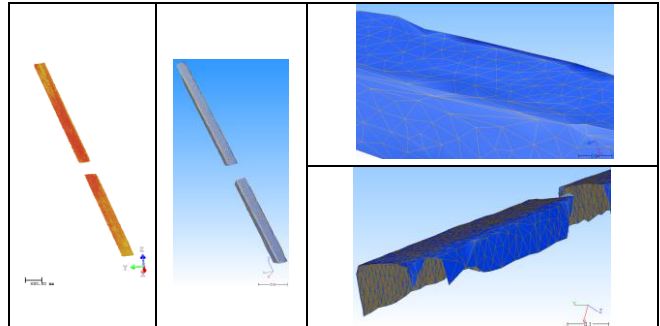
- 1/ derived polygon meshes from point clouds,
 - 2/ manual profile extraction and polygon meshes,
 - 3/ manual profile extraction and planar faces,
 - 4/ use of “EasyProfile Tool”,
 - 5/ four plane model,
 - 6/ reference face extruded model,
 - 7/ automatic constrained reference face extraction,
- A last method using the “Photomodeler” software was also tested.

3.1 Derived polygon meshes from point clouds

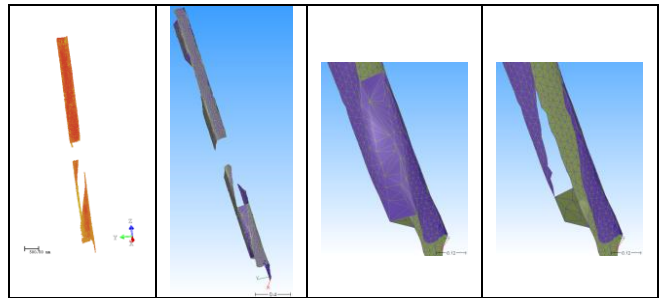
The first method tested consisted in building a polygon mesh model directly derived from the segmented point clouds. The used software was Technodigit's “3DReshaper”.

The segmented point clouds were imported as ASCII files. For the first example showed in Figure 5 - concerning the beam 111CF1 - the segmented point cloud is not noise reduced. The software reduced the number of points taken in account according to parameter defined by the operator. Figure 5a shows the initial point cloud. Figure 5b shows the polygon meshed beam object. Figure 5c is a detailed view of the result in which it was possible to detect false defines vertices. The Figure 5d of the same result shows the problems the automatic mesh method had to model the partially not visible faces of the beam. The second example showed in Figure 6, concerns the beam 111CH3. In this example, the polygon mesh could be completed automatically by using appropriated parameters. It was also easy to delete wrong triangles.

This method is very fast (some minutes), and automatic if no modification or complement is required. The obtained objects are very detailed but the files also very heavy because of the very high number of polygons (about 2500 per beam). The vertices of the hidden faces are not easy to complete, but the polygon mesh model can easily be modified.



Figures 5: a/ initial segmented point cloud, b/ polygon mesh, c/ errors, d/ hidden faces.



Figures 6: a/ initial segmented point cloud, b/ polygon mesh, c/ errors, d/ removal of wrong triangles.

3.2 Manual profile extraction and polygon meshes

This method consisted in the manual extraction of profiles from the segmented point clouds. This extraction of profiles was performed in “Trimble Realworks”. Then the profiles were transferred to “3DReshaper” where the building of polygon meshes connecting the profiles was automatically realized. The profile extraction needed the definition of a local reference system associated to the beam. The number of extracted profiles was defined by the user. The method was quite rapid and easy to use. The obtained beam object is not to heavy and contains about 200 triangles. The method crashed with some examples if the profiles are not regular. Like in the first method, the polygon mesh could be completed automatically by using appropriated parameters. It was also easy to delete wrong triangles. Figure 7 shows some results.

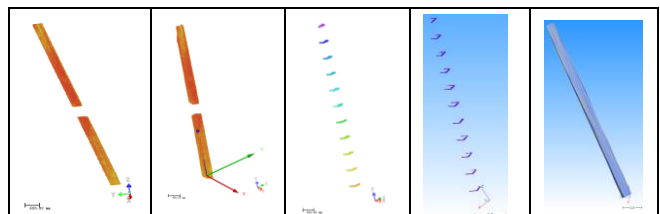


Figure 7: a/ initial segmented point cloud, b/ new local coordinate system, c/ profile extraction (Realworks), d/ profiles transferred (3DReshaper), e/ polygon mesh.

3.3 Manual profile extraction and planar faces

This method tested was like the second explained before but instead of using polygon mesh as structure for the model, we used planar faces which were simple and light structure to use in the future GIS integration. The workflow of this method contained more steps and took longer time (about half an hour per beam). The initial point cloud was segmented into beam object cloud. A new local coordinate system was defined. Then the manual method of profile extraction was used. Between two following profiles, the best planar face was fitted to each couple of profile vertices. The none measured face was then manually added. The four faces were adapted to the modeled beam part. Finally, the model was transferred to "Sketchup" where each part was assigned to a specific layer according to the accuracy (point to face approximation), the origin of data (measured or extrapolated) and the code of the beam. We used the same couple of software packages, "Trimble Realworks" and "3DReshaper" for these tests. The Figure 8 is an illustration of the different steps.

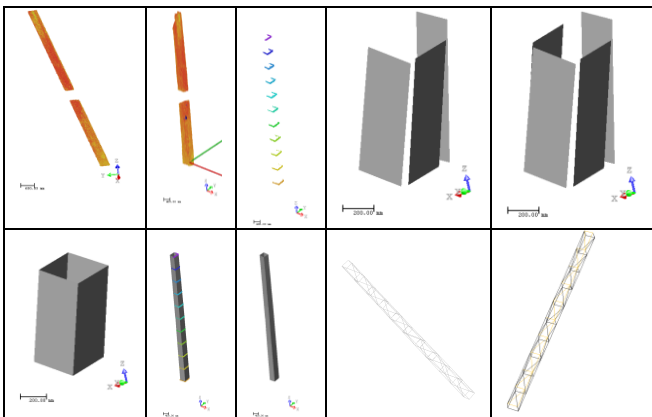


Figure 8: a/ initial segmented beam cloud, b/ new local coordinate system, c/ profile extraction (*Realworks*), d/ planar faces between profiles, e/ extrapolation of not visible face, f/ four faces adaptation, g/ faces and profiles, h/ beam model, i/ beam model in CAD system, j/ structured (layer & code) beam model.

The structured beam is directly usable and transferrable into a 3D GIS. The model is light because it contains only about 100 triangles par beam, depending on the number of profiles defined and the expected accuracy. The model is detailed and has a good render possibilities for curvatures and deformations of the beams. The model is also adaptable by choosing a greater number of profiles. The missing faces are easy to add in the model. But, this modeling process is quite long and not adapted in the context of our project which contains more than 600 beams.

3.4 Use of "EasyProfile Tool"

The inconvenience of the former method 3.3 is the long process time. To accelerate the profiles definition, we tested the "EasyProfile Tool" in "Trimble Realworks" software. This tool adapts a user defined profile along a point cloud. It is primarily implemented for pipe extraction but with regular beam profiles it was interesting to test it. From the beam segmented cloud, the first step was to extract the theoretical profile. Then, the tool should work automatically along the cloud. But with big holes

the process doesn't work very well. So it was necessary to proceed with continuous clouds or to use the process partially. For the beam 111CF1 (Figure 9 a/ to e/) which is not very regular, the hole detection failed and it was necessary to proceed in two steps. For the beam 111CH3 (Figure 9 f/ to j/) the result was quite good.

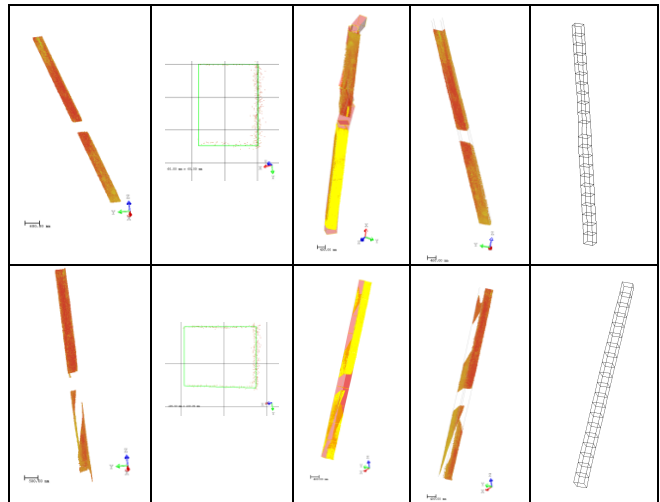


Figure 9: With 111CF1 beam a/ initial segmented beam cloud, b/ automatic profile definition, c/ wrong profile process, d/ two part process, e/ result in CAD structure. With 111CH3 beam f/ initial segmented beam cloud, g/ automatic profile definition, h/ good profile process, i/ profile result, j/ result in CAD structure.

3.5 Four plane model

Another tested method takes advantage of the automatic plane to point cloud adjustment tool available in the software. In this case, the beam is considered as a simple box bordered by four (plus two) planes. The method is very fast. We had to find out the four best fitted boundary planes, to intersect them and to create the beam object. The obtained model is light (four planes), defined semi-automatically. The addition of the extrapolated fourth face is easy. But the method is missing of beam details, no curvature can be modelled. This method can be retained for the definition of a fast but very low detailed model in 0+ version. Figure 10 shows the different steps of the method described for the beam 111CF1.

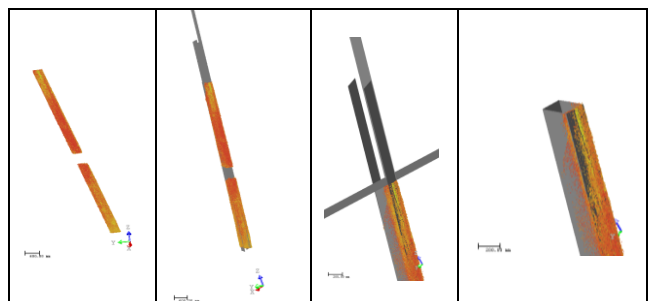


Figure 10: a/ initial segmented beam cloud, b/ automatic four plane definition, c/ definition of a cutting plane, d/ beam model as four adjusted planes.

3.6 Reference face extruded model

This tested method gives as hypothesis that a beam is a solid piece of wood, and that all the deformation are regularly transmitted to all faces. So if one face is accurately modeled, the other faces can be derived by using an extrusion tool (Figure 11). The reference face has to be a lateral face of the beam so that the extrusion length can be measured along the third acquired face. The last face (not visible) is automatically generated by the extrusion process. For the measurements in the point cloud and for the reference face drawing, the “Trimble Realworks” software was used. The reference face was then imported into “Sketchup” to perform the extrusion. The resulting model is light depending on the form of the beam (with or without many deformations). This method is fast (a few minutes to model a beam), is adaptable if the more details are expected. But only one width can be used for the beam, this restriction should not be a problem in our project. If the chosen modeling system is “Sketchup”, we have to change the coordinate system and work in a local one for each beam.

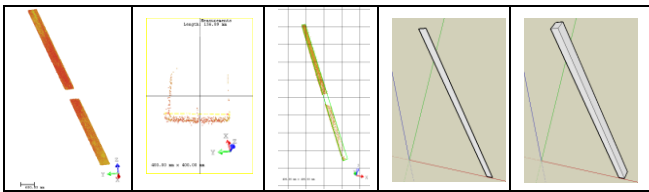


Figure 11: a/ initial segmented beam cloud, b/ size measurement, c/ principal face contour drawing, d/ face export (Sketchup), e/ beam extrusion.

3.7 Automatic constrained reference face extraction

After testing these six former methods, which are adapted to different versions of the model depending on level of detail, accuracy, we decided to improve the model generation. Finally, the previous 3.3 method seems to be the best adapted to our expected model, but was based on a long manual measurement and modeling phase. This last method developed, used a developed “MatLab code” to extract automatically the reference face as a polygon mesh between profile lines. The reference face extraction can be constrained by distance between following profile lines, curvatures of the beam, and so on.

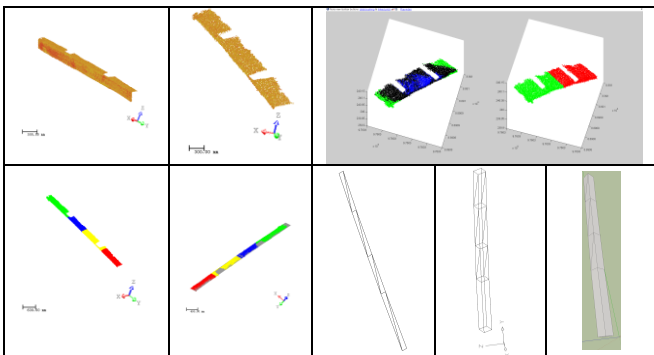


Figure 12: a/ initial segmented beam cloud, b/ segmented beam reference face, c/ result of “MatLab” processing, d/ colored segmented beam cloud, e/ multi-plane adaptation, f/ multi-plane decomposition in CAD environment, g/ multi-plane extrusion, h/ final beam in “Sketchup” environment for structuring.

This workflow uses “Trimble Realworks”, Mathworks’ “MatLab” and “Sketchup”. The advantage of this method is the possibility to enter as parameter the type of the expected beam. The initial point cloud has to be segmented to extract only the reference face. Then the “MatLab code” decomposes the plane into several parts depending on the firstly entered parameters. For each different part, a plane face is adjusted (best fit), and then the multi-plane face is generated. This multi-plane face is then extruded to the definitive beam model.

3.8 Comparison of different methods

The following diagrams (Figure 13) give a synthetic view of the different methods, their advantages and disadvantages in terms of processing time, automatism, result file size (depending on structure and number of faces or polygon meshes generated), level of details, ability to apply corrections easily, ability to manage missing faces.

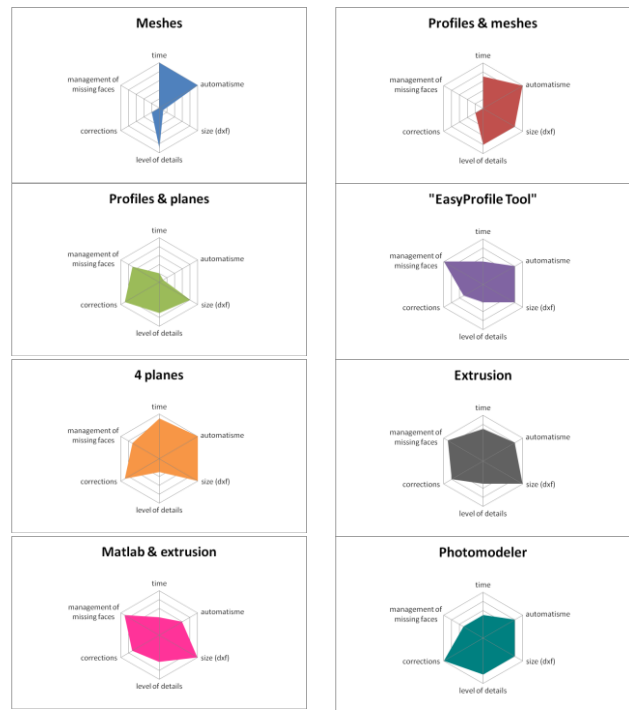


Figure 13: comparison of different modeling methods

3.9 “Photomodeler”

The last diagram (Figure 13) is applied to tests done with “Photomodeler” software and was used to model other complex structure elements. The Figures 14 shows the field acquisition using frames for the automatic geo-referencing operation. Long time manual processing gave good results particularly for objects with curved parts.

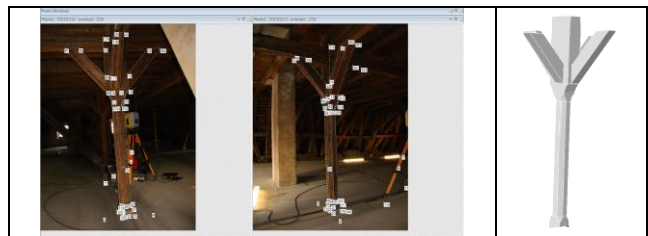


Figure 14: a/ homologous point acquisition, b/ CAD result.

A positive point is the automatic texture application possibility offered by this solution, but poor lighting conditions generated some difficulties while the data acquisition.

4. 3D GIS INTEGRATION

The 3D model of the entire frame was integrated in a light 3D model of the whole building (Figure 15). The beam numbering method described in section 1 was used as the basic structure for a hierarchic 3D information system of the frame. To increase the knowledge of the frame structure and composition, diverse material and documentation were associated to each beam. GIS allowed also to animate the different layers and to construct a 3D animation showing how the frame was historically assembled. Now, the GIS will be the basic tool used for the interpretation of the historic building and construction methods. The frame model from real measurements, state of the structure after 400 years, allowed the comparison to a theoretical model.

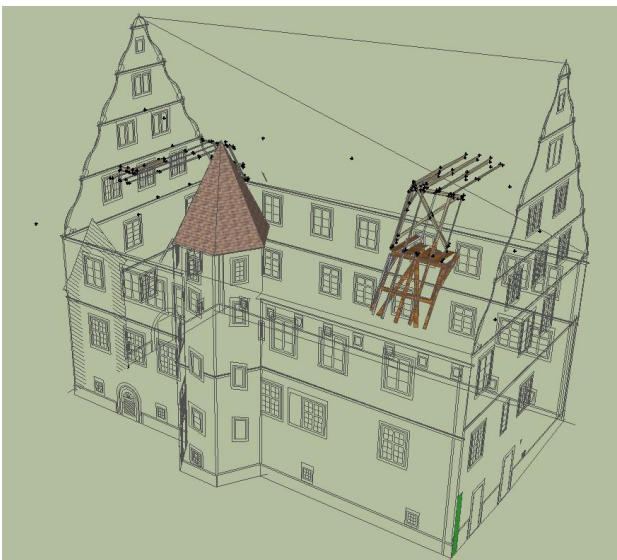


Figure 15: partial timber work integration in whole model of the “Seigneurie”.

The Figure 16 shows the theoretical model of the first upper floor, integrated into a GIS.

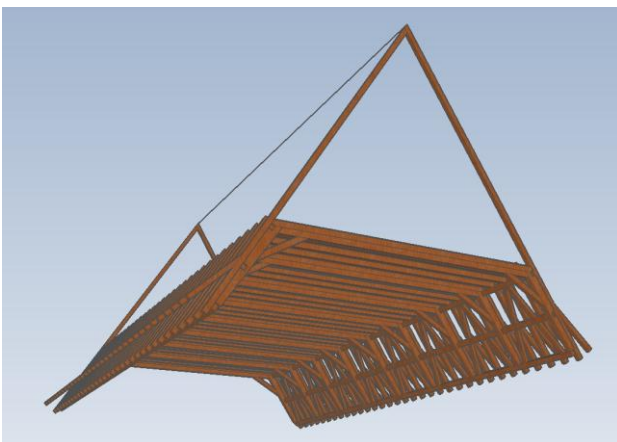


Figure 16: Theoretical model of first floor.

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