3D Digitization of the Brussels City Hall and the Medieval Archangel Michael Wind Vane: Architectural and Archaeological Exploitation

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In order to make the architectural and archaeological study, the roofs, the courtyard and the facades of the Brussels City Hall were digitized with a 3D scanner, coupled with photographic acquisitions. Various elements, such as the main portal tympanum and the archangel Michael – an exceptionally preserved 5-metre-high medieval metal wind vane that adorned the top of the 96-metre-high tower – were also digitized in high definition. Numerical surveys show different colorimetric (variation of colorimetry related to the changes in natural lighting) and geometric defects (erroneous points related to the passages of persons and vehicles, flying points or noises inherent to the acquisition device). A specific and automatic processing pipeline has therefore been developed and applied to correct all these problems. Given the amount of data and operations for creating plans, a software has been developed to present the data as an enriched 2D representation. This is similar to orthophotos complemented by the possibility to navigate in the depth and to vary the rendering mode (color, intensity, orientation ...), to highlight elements (surfaces, edges ...) hardly visible in simple color mode of rendering. Its functionalities allowed the realization of very precise elevations and to generate projection images in high definition of all buildings parts and also of the archangel statue. Indeed, this survey allowed drawing the entire statue to the real scale and in a completely proportioned way. Archeologists have been able to distinguish the main work components, and they better understand the articulations between its constitutive parts and the various transformations made to the metal statue over the centuries.

Key words:
3D scanning, automatic pipeline, archaeological exploitation, multimodal rendering.

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INTRODUCTION

For many old buildings, such as the Brussels City Hall, there are no more architectural plans reflecting their current state. It is therefore necessary to carry out a measurement survey in order to obtain precise plans of roofs, facades and room configuration, for different purposes like the architectural studies, some major renovations, or the monitoring of its evolution.

In many cases, facade survey missions ordered to professionals are carried out at a predefined resolution; it is impossible to obtain measures that would not have been planned at the beginning of the project. One of the goals of our project is to develop a complete solution to extract the necessary measurements from 3D acquisitions, in formats compatible with standard software used in the architectural field, and to be able to supplement them later with information about details, according to new needs. The tool developed must also consider the very large volume of data to be processed, while ensuring easy and fluid handling for non-specialized users.

About the medieval archangel Michael wind vane, the archeological goal of the project is to obtain a three-dimensional model faithful to reality, usable to evaluate archaeological hypotheses: renderings of the original aspect of the materials, variations of armaments (e.g. a spear instead of the sword).

The position in the center of Brussels and the accessibility of the building limited the type of usable acquisition device to long range scanner to cover a maximum of the surface. Likewise, the size of the wind vane limits the usable digitalization processes. Indeed, terrestrial and aerial photogrammetry require accessibilities and access rights limiting their practical use in the field.

Brussels City Hall and Medieval Wind Vane Acquisitions

The Brussels City Hall, as it can currently be seen, is the result of different phases of construction, described in Fig. 1, followed by restorations. The first part dates from the 15th century. It was built in Gothic style and extended to keep a harmonious style. The entire building was completed in 1455, by raising the tower and placing the statue-vane of Archangel Michael at its summit. The City Hall was restored a first time after the bombardment of Brussels in 1695 by the French army. The second wing was built then, lower than the rest of the building and arranged in a U-shape, delimiting a courtyard.

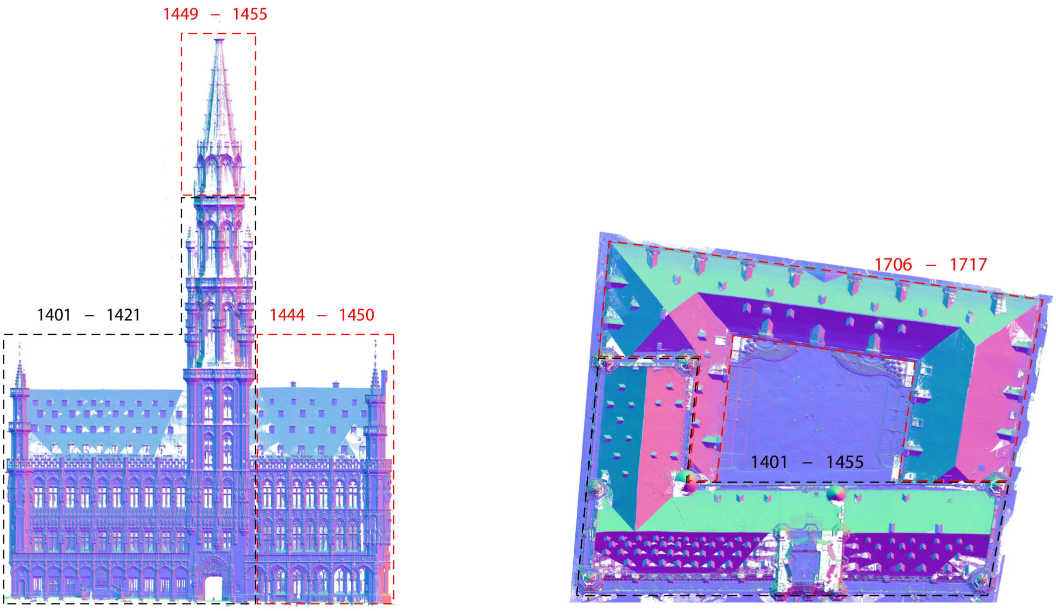


Fig. 1. Construction steps of the Brussels City Hall. a) View of the front façade and b) aerial view. The models correspond to the data acquired and are colorized according to the normal of the points. For rendering, each component of the vector obtained is normalized and represented by a different color channel

During the 19th century, the facades underwent various restoration campaigns (including the replacement of the original sculptures by copies), as well as embellishment campaigns. Thus, 294 new statues, personalizing former Brabant rulers and their families, important magistrates of the City and personalities from fine arts, gradually come to fill the numerous niches remained empty since their construction.

In 2015, two survey campaigns made possible to obtain all facades and roofs of the Brussels City Hall as a big point cloud (see Fig. 2). A FARO S120 3D Scanner was used in order to acquire all points in high definition with a 0.035° step angle for global acquisitions and a 0.0175° step angle for details. The second configuration is defined to have some parts in higher resolution for algorithm testing. No targets were used in the acquisition because the point density was high enough to register scans by only using geometry.

Fig. 2. Point cloud of the Brussels City Hall acquired with a Faro S120 3D Scanner

The acquisition of the building presents some difficulties inherent to its position in the historic center of Brussels:

- Placement limitations, inducing the presence of geometrical shadows in the model and a resolution limitation: the front facade is far from the nearest building and conversely the side facades are close to the neighboring buildings, which imply the impossibility to have some direct front views or elevated views. The balcony at the base of the roof is obstructed, limiting access to some interesting views (for example, the roof areas at the base of the tower);
- Range limitation: the tower is very high (nearly 100 m) and was not the main object of interest of our study, so it is difficult to obtain a high resolution of this part, without allocating a lot of resources (staff, equipment, time …), and the same problem applies to the statues of the facades;
- Limitation due to pedestrian traffic: many acquisitions have been made from ground areas (from the square, the surrounding streets and the inner courtyard) which cannot be closed for tourists.

In total, 97 scans positions were necessary to obtain the external building. However, due to the building complexity and the difficulty to have good viewpoints with valid ranges and good incidence angles, some geometries have not been correctly acquired. Moreover, some details were acquired in very high definition (see Fig. 3), such as the main portal tympanum, the lion statue located in the gallery of the left wing, or a column in the gallery of the right wing.

a *b*

Fig. 3. High resolution 3D scans of details of the Brussels City Hall: a) main portal tympanum, b) the medieval archangel Michael wind vane with the positions of the scanner acquisitions

The medieval archangel Michael wind vane, patron saint of Brussels, was installed in 1455 at about 97 m height, on the point of the belfry of the City Hall. In 1993, the original version of Martin Van Rode, too altered to be restored a second time, was sheltered in an inner room of the tower and replaced by a copy. The entire statue, from the base to the tip of the sword, is nearly 5 m high. The digitalization of the medieval archangel Michael wind vane took 13 scan positions in order to obtain a high-resolution model of this statue (see Fig. 3(b)) in natural light conditions with the FARO 3D. But, considering the height of the object and the absence of a plunging point of view, the upper part could not be scanned.

In addition to the geometry acquisition, pictures were taken by the scanner in order to colorize the point cloud. In order to do that, the FARO 3D scanner is equipped with an integrated camera located near the optical center of the device that allows associating color information for each 3D point. Table 1 gives a summary of all acquired data, where the valid points only correspond to the ones inside the object of interest. For example, it is nearly impossible to limit the acquisition to the building facades without acquiring other nearby facades.

Table 1. Information about acquired models

3D Model	Number of scans	Number of 3D points	Number of valid 3D points	Number of pictures
City Hall	97	2.7 Billion	1.8 Billion	5841
Wind vane	13	228.9 Million	228.3 Million	377

DATA PROCESSING

In variable and uncontrolled light conditions, for big complex outside sites, the 3D models acquired with laser scanners and cameras have a lot of geometric (like noise, flying points, outliers, moving objects) and colorimetric (like overexposure, light variation, shadows) defects.

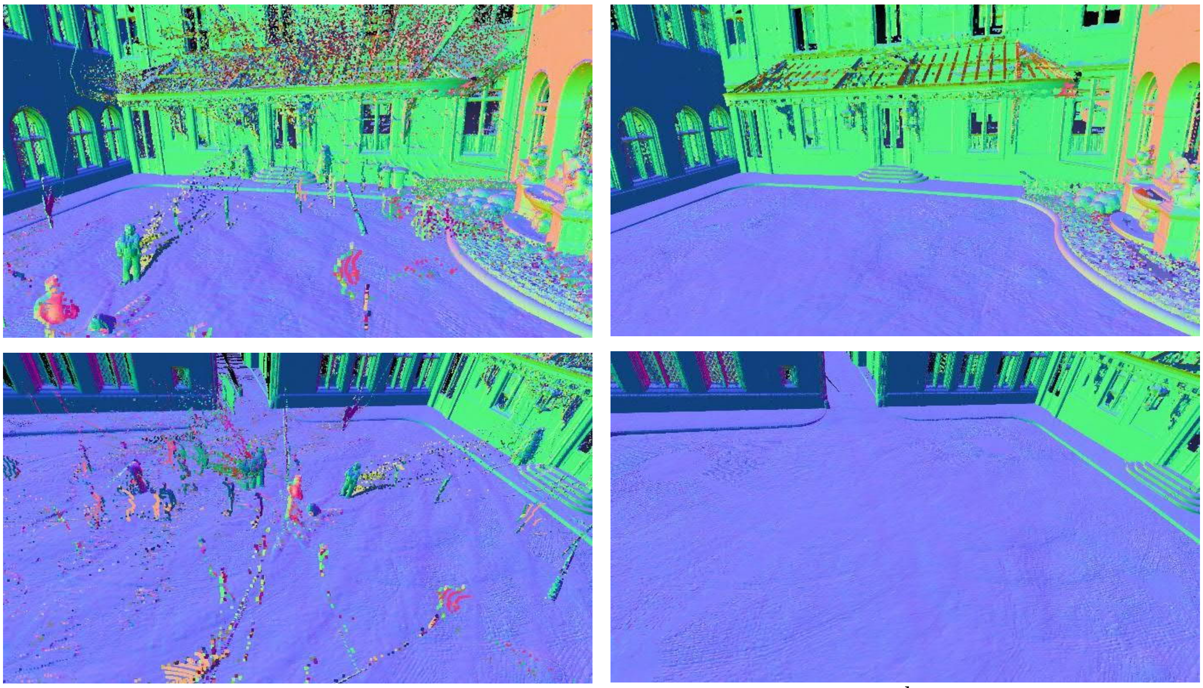
In point clouds, considering the use and the precise alignment of several scans, different forms of artifacts may appear; but it is difficult to associate a precise and unique consequence with each existing source of errors [Schenkel 2017]. Several consequences are frequently observable:

- Measurement noise is generally considered as randomly distributed points near the surface (front or back). In scanner acquisitions, it is introduced along the line of sight according to a specific distribution of the distance-dependent error, which depends on the acquisition tool (sensor noise, quantization error), the methodology (distance and orientation of the scanner with respect to the surface), the environment (attenuation of the signal in the air) and the target (properties of the surface, diffusion characteristic of the materials);
- Outliers occur when ideal conditions are not met and are therefore almost unavoidable artifacts of acquisition systems. From a geometrical point of view, the outlier values in a point cloud are the measurement that are not part of the digitized area and should be removed;
- Flying points appear separately from other points in positions where no surface exists in reality. They occur on the edges of objects where there is a sudden change in depth from one object to another, where the surfaces of the two objects influence the measured depth value so that the obtained value approaches a weighted average of both distances. These artifacts tend to become systematic with the increasing of the angular resolutions and of the measurement distances;
- Inconsistencies in the scene. For building acquisitions, several scans are needed, but can spread widely over time. It is not always possible to ensure a complete closure of the site to visitors or that no equipment or objects are moved during this process. This leads to inconsistencies in the scene or ghost geometries that are captured only in a single or a small number of acquisitions. All objects that are not persistent in the scene can therefore introduce artifacts into a scan that can dramatically compromise the quality of the results.

An automatic pipeline has been developed in order to cope with these problems [Schenkel 2017]. In order to correct these defects, the data processing was based on a point description of the acquisitions since 3D points are obtained as raw data from a laser scanner and also because correct visual renderings can be easily computed from points. Due to the big size of the models, the measures are structured as multi-data layers maps (e.g. ranges, point colors, etc.) for each scan position, allowing to easily load and treat them in the computer memory. This structure corresponds to the original data format, avoiding a multi-scale data transformation (e.g. octree) that would take a lot of time, without any advantage for our application.

The method for detecting flying points in each scan position is based on the distribution of the points with respect to the acquisition center, more precisely by using a threshold on the angle between the normal of the point and the scan viewpoint. The identification of inconsistencies in the point cloud (i.e. moving points) is based on the comparison between all acquisitions of the zone of interest and on common ideas of [Kanzok et al. 2013] and [Zeibak and Filin 2007], without the necessity of data restructuring. A majority vote approach and the comparison of local features taking into account several criteria (position, normal, color, etc.) allows good identification of outliers, while avoiding misidentification and deletion of too many valid points.

Fig. 4 gives two examples of a render in false colors (corresponding to the normal) for the City Hall courtyard before and after cleaning the geometric defects. The presence of the different types of geometric errors can be easily observed: flying points are present above the glass veranda; silhouettes show the presence of visitors during the survey, different objects along the facade (plants, trash cans) were also moved between the acquisitions. All these problems are handled correctly.



a *b*

Fig. 4. Cleaning of geometric errors (flying points, moving points and inconsistencies) for the City Hall courtyard: a) Raw points clouds, b) Points cloud corrected with the proposed method

Without complementary processing, variations of light conditions during acquisitions cause an unpleasant geometric rendering (see Fig. 5a and 5c). In order to cope with this problem, an original colorization method, based on Baumberg [2002], Callieri et al. [2008] and Pintus et al. [2011] research, has been developed. In summary, the point color is obtained by using all available pictures and by weighting them with its respective local quality as explained in [Schenkel and Debeir 2015] and taking into account the intrinsic picture quality (shadows presence, overexposure, etc.) but also the pictures capture conditions (source position and orientation with respect to the geometry, or the model silhouette in relation to the view point). Fig. 5 shows this problem with its corrected result.

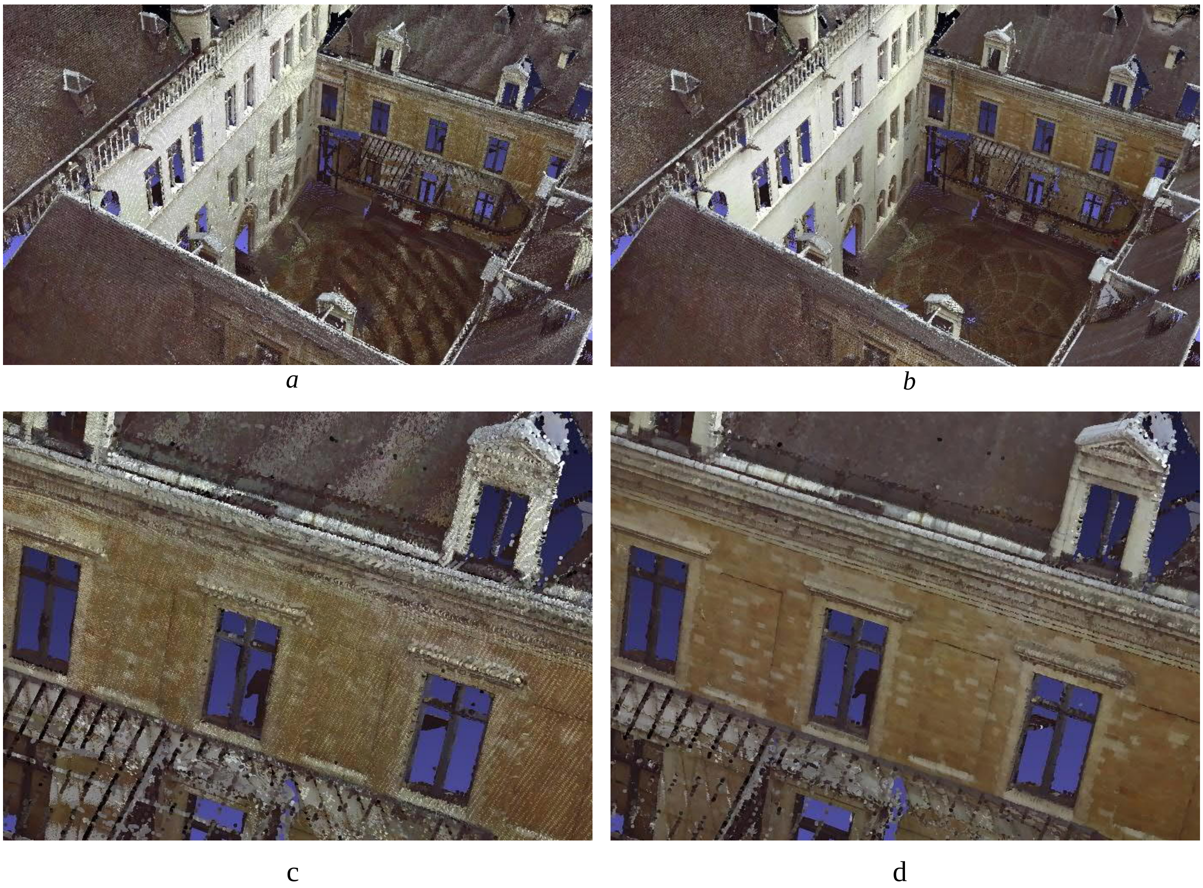


Fig. 5. Example of color correction for the City Hall Courtyard: a) & c) Raw points cloud, b) & d) Corrected colors model

ARCHITECTURAL EXPLOITATION

Many software solutions exist on the market, but they often have different limitations for the users:

- in 3D view, the data manipulation can cause some confusions: transparency within a point-based model, difficulties to identify neighboring elements, human-computer interactions to correctly orient the view, ...
- the amount of data to be manipulated involves octree-based data restructuring or similar approach, so all points are not directly and necessarily displayed, often imputing repetitive data loading times with each move or manipulations ;
- the point cloud colorizations are limited to some basic information, such as color, height, intensity... while information like the normal to the surface, yet elementary for the geometric extraction, is largely ignored...

The software LisaCAD (see Fig. 6), named from the contraction of the LISA department having developed the solution and computer aided design or CAD, was created specifically to meet the needs of the architects of the City of Brussels, in order to use 3D scans to establish accurate plans of the Brussels City Hall.

In order to do that, the scans are projected in a grid discretizing a projection plane and corresponding to a cut plane, a facade elevation or any other plane of interest. Each grid element has several projected points at different depths (in a selected range, generally 0 to 11 m to the plane) that allow to interact with the point distance to the plane and the angle between the normal of the point and the plane normal, for example in order to display the balconies and what is behind them. So, only the first grid element (point) in the selected depth range and normal angle can be shown as an image pixel.

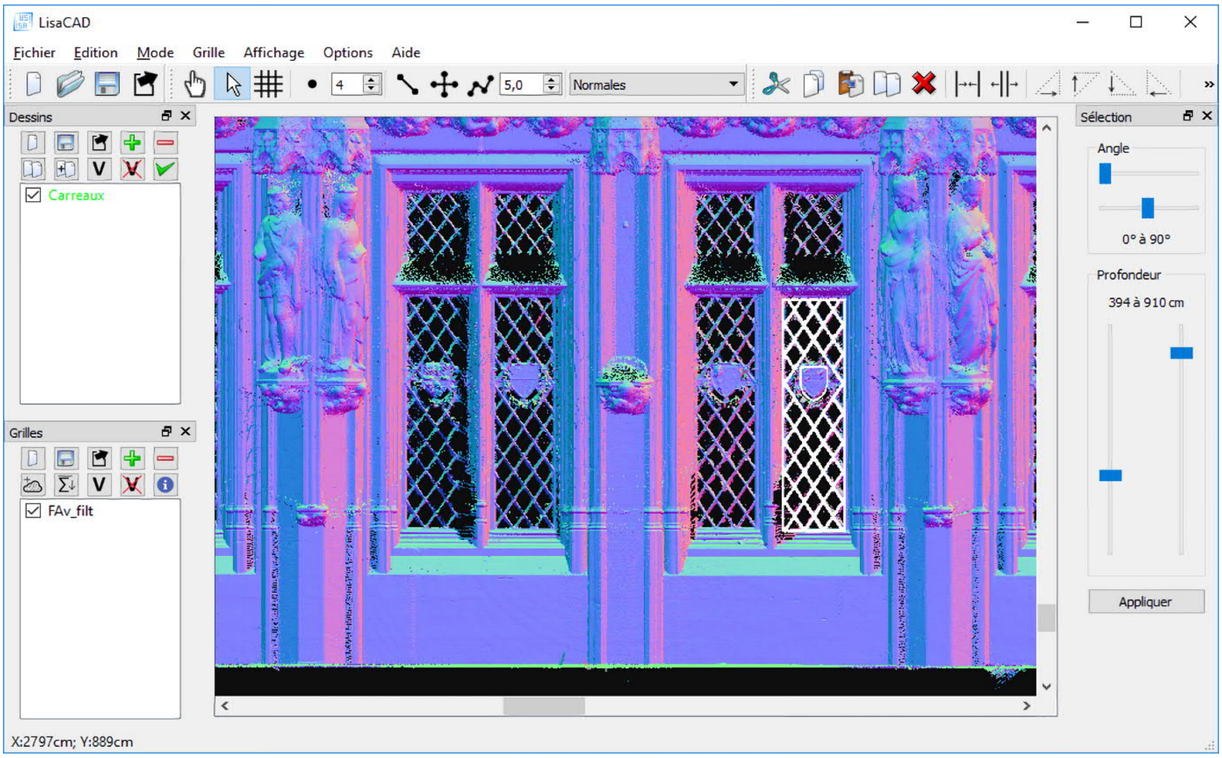
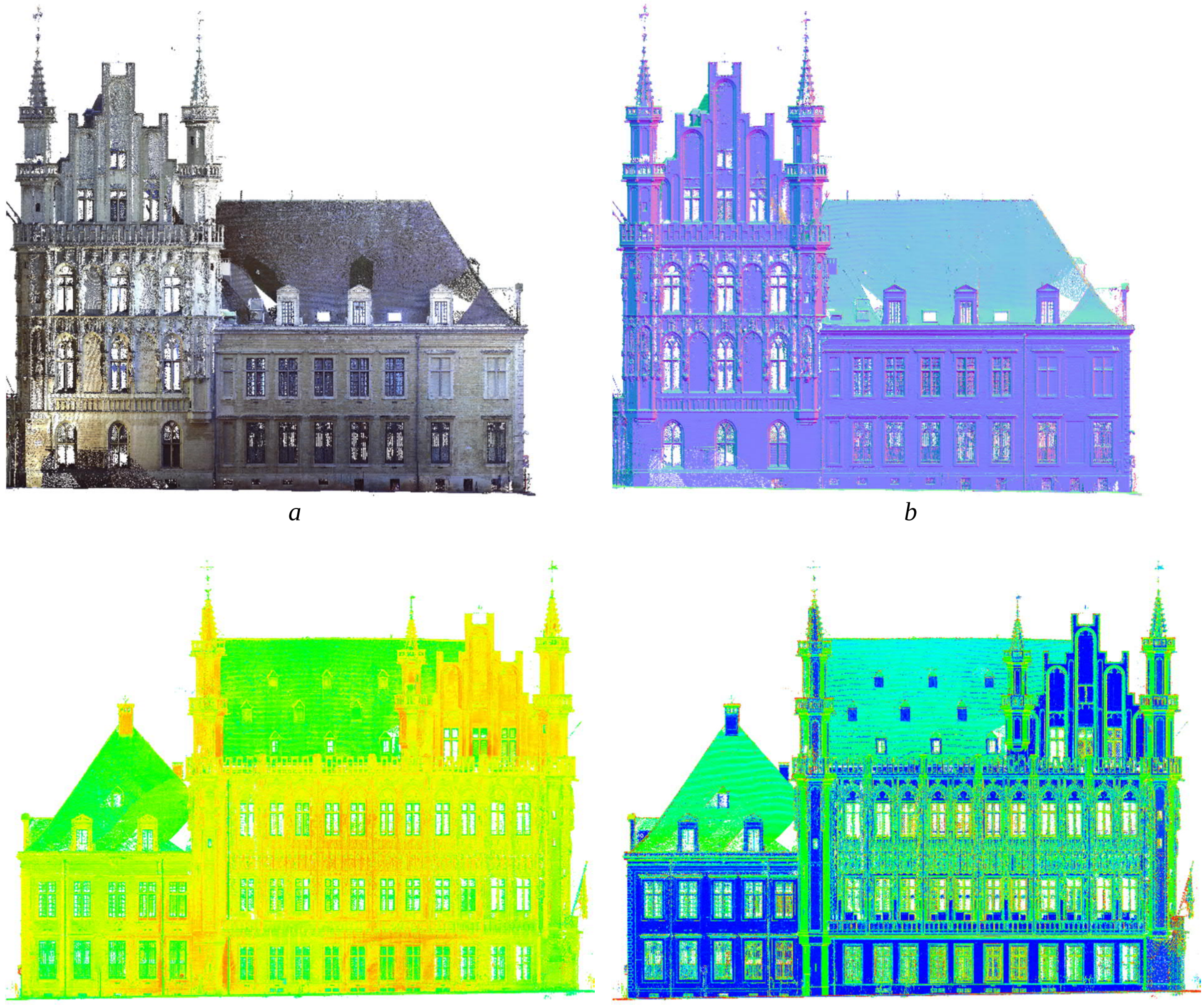


Fig. 6. LisaCAD screenshot with the front facade windows in normal color where a stained-glass window is drawn in white color

Each point contains different interesting information that can be displayed in true or false colors (using a color pallet) depending on the selected display mode e.g. picture color, infrared laser intensity, depth/distance of the point from the plane, point normal, etc. (see Table 2 for all available display modes). The software can export these grids as images displayed in LisaCAD. Fig. 7 shows several examples of images obtained in different display modes for the Brussels City Hall. In this case, a grid element (pixel) represents a resolution of 1 cm^2.

Table 2. Available grid display modes in the software LisaCAD

Display mode	Description
Color	Point true color taken by the integrated scanner camera.
Intensity	Infrared laser intensity measured by the 3D scanner, in grayscale color. This mode gives some information on the material type (concrete, wood, etc.) and its color, as a black and white picture, but without the influence of external light.
Normal	Each RGB color channel of the grid element corresponds to a component of the point normal, respectively red for the x component, green for the y component and blue for z component. This mode highlights the reliefs.
Absolute normal	Each RGB color channel corresponds to the component absolute value of the point normal. This mode highlights the parallel surfaces to the projection plane in blue color and the perpendicular ones in green color for horizontal and in red for vertical.
Angle	Angle between the point normal and the projection plane normal. This mode highlights the identical surface curvature by its similar color.
Depth	Distance/depth of the displayed point. This mode highlights the nearest point to the projection plane (in blue) with respect to the furthest point to the projection plane (in red).



a b c d

Fig. 7. Facades projections (grids) of the Brussels City Hall in several display modes: a) Right facade elevation (Rue de la Tête d'or) in true color, and b) in normal color. c) Left facade elevation (Rue Charles Buls), and d) in angle color

In the software LisaCAD, grids are used as drawing background in order to create vector plans composed of geometric primitives that can be imported in CAD software such as AutoCAD. Fig. 6 gives a screenshot of the software; a front facade detail is used as background in order to draw stained glass windows.

Based on existing projections, new grids can be easily generated. First, if the resolution is not enough in a part of the grid, the architect can generate a new grid with higher resolution for all the projection or a part of it (rectangle selection). For the same plane of projection, several grids can be loaded together in the software. Nevertheless, if the resolution is too high with respect to the points mean distance of the original point cloud, a lot of empty grid elements (i.e. transparent/background color (black by default) image pixels) will be present and this is not interesting. Secondly, it is also possible to generate a new grid that is perpendicular to the current projection only by drawing a line that corresponds to a vertical plane. So, the architect can easily manipulate and generate new grids based on the existing ones that were e.g. mathematically obtained for facades (best fit plane). This operation is really easy for the architect because no hard 3D manipulation has to be done.

This software was intensively used by the City of Brussels in order to draw precise plans of the Brussels City Hall and all its facades (see Figs. 8 and 9).

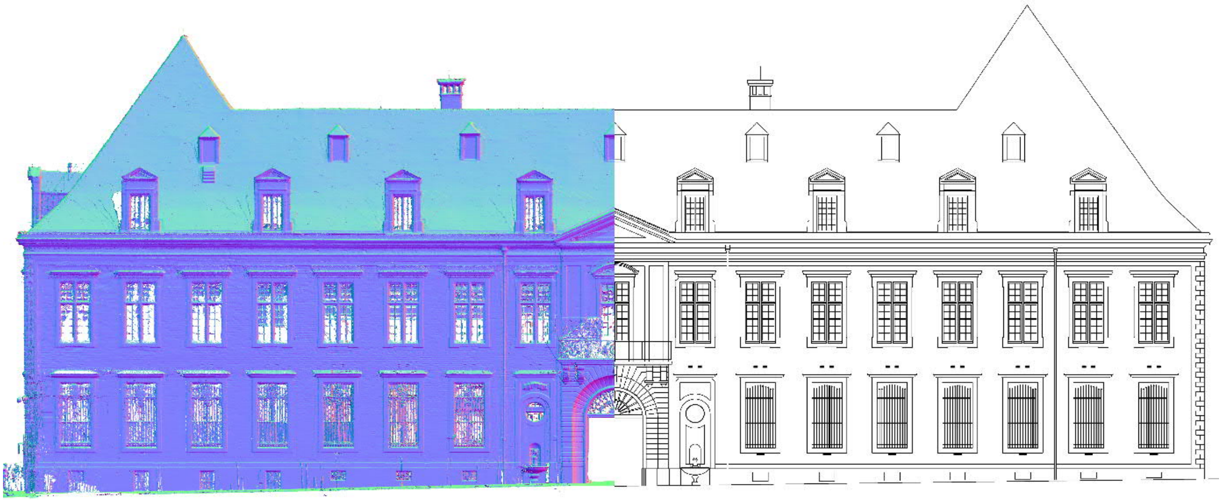


Fig. 8. Rear facade elevation: grid in normal color vs. drawing (©Ville de Bruxelles - Patrick Moureau's drawing)

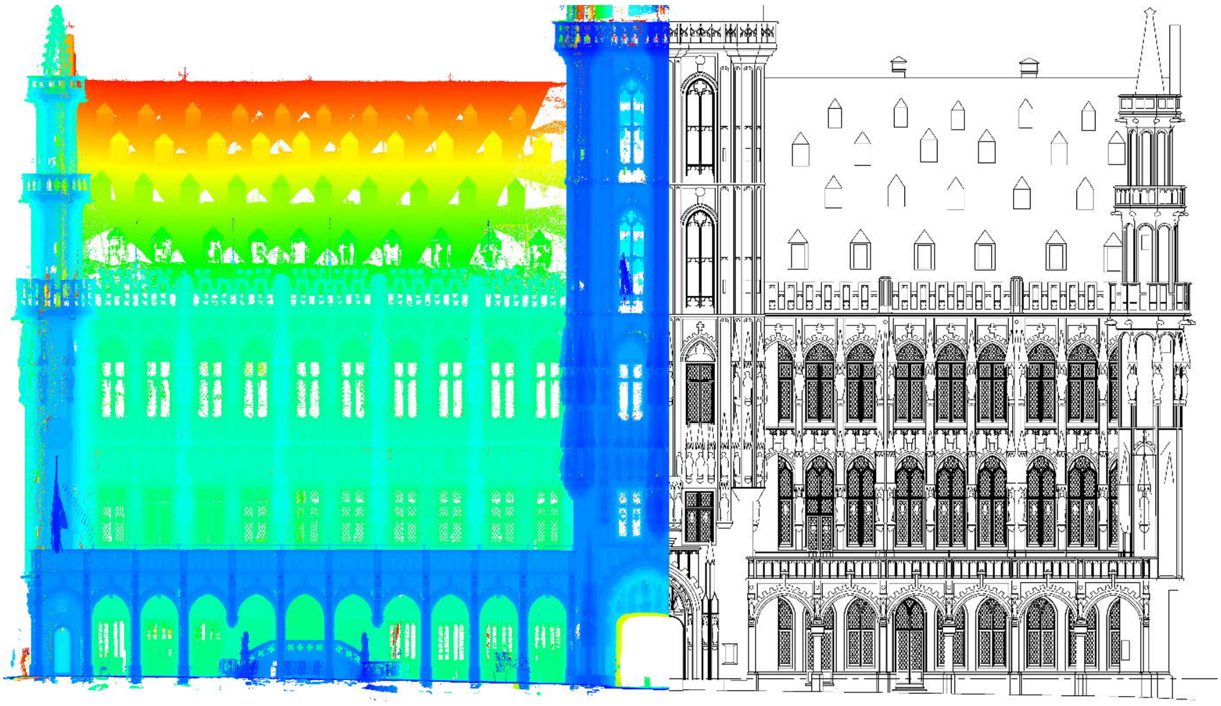


Fig. 9. Front facade elevation: grid in depth color vs. drawing (©Ville de Bruxelles - Patrick Moureau's drawing)

ARCHAEOLOGICAL EXPLOITATION

The developed software was also used with the archangel Michael scans, in order to generate projections in high definition giving complementary information for archeologists (see Figs. 10a and 10b) by placing elements, indices or hypothesis on these projections illustrating the research. Indeed, it allows archaeologists to draw the entire statue to the real scale and to distinguish the main work components with a better understanding of the articulations between its constitutive parts and the various transformations made to the statue over centuries. Moreover, the 3D model of the archangel statue was used as representations for videos and images but also to evaluate archaeological hypotheses: renderings of the original aspect of the materials (i.e. color restoration) (see Fig. 10c) or weapon variations swapping. One hypothesis is that the sword killing the dragon may have been a spear (thanks to its dating), but the adapted model shows that it was not the case due to the wrong relative position of the dragon with respect to the spear (see Fig. 10d).

Fig. 10. Exploitation of the archangel Michael 3D scans: a) front projection of the scans in normal color, b) side projections of the scans in normalized depth color, c) color restoration of the original statue, and d) sword replaced by a spear in the 3D model (draft rendering) in order to test this hypothesis

All these graphic documents are similar to an archeologist's survey, giving the material condition of the wind vane at a precise moment. They can support the restorers ‘condition report and serve as a basis for an analysis prior to their intervention on site.

CONCLUSIONS

In order to carry out its architectural and archaeological study, a large part of the Brussels City Hall and some of its elements were digitized in 3D. The different scans were processed by an original pipeline for cleaning the erroneous points but also to correct the colorimetry of 3D points. Then, these data were exploited architecturally in the LisaCAD software in order to draw precise plans of the Brussels City Hall. In parallel, some data has been exploited by archaeologists to provide additional information to their studies as well as to verify certain hypotheses. LisaCAD helps archaeologists to better understand the archeological artefacts by adding different comprehension layers and establish next acquisition strategies and future planning of restorations. This project shows the interest of architects and archaeologists in using 3D digitization to understand a building or its elements as a whole in order to carry out an accurate study or survey and updates old data by correcting ancient plans using scanner technology.

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REFERENCES

Arnaud Schenkel. 2017. Corrections géométriques et colorimétriques automatisées de modèles 3D de grande taille. *PhD Thesis*. Université Libre de Bruxelles. Belgium.

Thomas Kanzok, Falk Süß, Lars Linsen, and Paul Rosenthal. 2013. Efficient Removal of Inconsistencies in Large Multi-Scan Point Clouds. In 21st Intl. *Conf. in Central Europe on Computer Graphics, Visualization and Computer Vision*. Plzen. Czech Republic. p.120-129.

Reem Zeibak and Sagi Filin. 2007. Change detection via terrestrial laser scanning. In *ISPRS Workshop on Laser Scanning 2007 and SilviLaser 2007*. Espoo. Finland. p.430-435.

Adam Baumberg. 2002. Blending Images for Texturing 3D Models. In *British Machine Vision Conference, 2002*.

Marco Callieri, Paolo Cignoni, Massimiliano Corsini, and Roberto Scopigno. 2008. Masked photo blending: Mapping dense photographic data set on high-resolution sampled 3D models. *Computers & Graphics*. 32(4):464-473.

Ruggero Pintus, Enrico Gobbetti, and Marco Callieri. 2011. Fast low-memory seamless photo blending on massive point clouds using a streaming framework. *Journal on Computing and Cultural Heritage*. 4(2) article No. 6.

Arnaud Schenkel and Olivier Debeir. 2015. Comparison of normalized transfer functions for fast blending-based color correction of scans acquired under natural conditions. In *2015 Digital Heritage International Congress*. Grenada. Spain. p.127-130.

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