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DIGITAL SECURITY: 3D GEOMETRY PROTECTION OF THE AUTOMATICALLY RESTITUTED HISTORICAL BUILDINGS

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Abstract. *This paper describes a novel method of data protection of the three-dimensional (3D) models that are obtained from automatic process of geometric restitution, using old two-dimensional (2D) architectural and artistic drawings. The first contribution of our research is the algorithm that includes several image processing steps, which are required in order to define walls, staircases and openings from the digitalized hand drawn architectural plans. The result of this step is detailed 3D model of the digitally processed historical building plans. The experimental confirmation of the algorithm accuracy is 3D model of the Chateau de Versailles, which is descripted by old hand drawings, dating between the end of the XVII and the XIX century. Next part of our research is theoretical and mathematical analysis of geometrical features of such 3D model that is a result of the image processing algorithm. The key-achievement of this part is new method of protecting the geometrical data using optimized adaptive Sparse Quantization Index Modulation (QIM) for embedding data bits into essential structure of the generated model. As a final result we present a secure authentication of the automatically restituted 3D model of the historically important artifact.*

Key words: *3D geometry, 3D reconstruction, 3D restitution, cultural heritage, data protection, digital archive*

1. INTRODUCTION

Nowadays, three-dimensional (3D) representation is important part of many research processes. This perceptual experience is crucial for design and architecture, but it also becomes standard in the fields of medical diagnostic and physical simulations. Due to the

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rapid increasing of the Internet use, 3D virtualization is an unavoidable part of any cultural heritage representation. 3D models have been very useful for archaeologists and historians to imagine the disappeared appearance of some historical building and better understand and explain life in the past centuries. Furthermore, according to the old documents and plans, 3D virtual tours can create a perception of the authentic site and thus such 3D representation becomes an innovative tool for curators.

The most of 3D modelling techniques in the field of cultural heritage restitution are based on laser scanning and photogrammetry [1, 2, 3, 4]. In combination with CAD software and image processing techniques, we can reconstruct the appearance of partially disappeared monuments [5, 6], but with great amount of manual operations, both in digitalization and virtual reality steps. In the field of data protection, especially watermarking, there are plenty of research papers that address theoretical issues of data hiding in 3D geometry [7, 8, 9, 10, 11, 12, 13]. However, in our knowledge, there is no adequate method of inserting data into the unique geometry of the automatically restituted historical buildings.

This paper presents a new method of inserting data into the geometric structure of the restituted cultural heritage 3D model. Through the combination of algorithms that automatically generate 3D models from a collection of old architectural plans and sparse quantization step for the inserting data, we introduce a new 3D modelling and protection techniques.

2. Related Work

Automatic 3D visualization from two-dimensional (2D) architectural drawings is an active research field since the end of XX century. Thus, 3D architectural representations become essential part of architectural planning process that allow architect an intuitive perspective of their work [14].

In most methods, automatization processes firstly detect and separate graphics and texts from the plan. Then follows a detection of the straight lines and localization of the structural elements using mathematical morphology or Hough transforms [15, 16]. Analysing the connectivity of segments and recognizing key symbols that are approximately convex regions or SURF key-point, the extraction defines the room boundaries. Applying OCR to the text layer gives the room functions. Finally wall extraction provides a final 3D model.

According to [17], architectural drawings that are used for generating 3D models can be divided in three categories: structural (building structures), functional (doors, windows, elevators, etc.) and decorative (dividing walls, lights, etc.). Therefore, the system contains three main steps to process the drawings: shape analysis, recognition and detection of the structural elements; the removing of the graphic primitives that correspond to the recognized shapes; and finally the symbol recognition algorithm for the architectural entities detection.

The main difficulty of the first task is dealing with imperfections of old architectural plans that are used as a base point of the automatic process. Straight lines are not enough straight, unnormalized symbols and texts, unequal line thickness, paper watermarks and folding are some of the characteristic examples (Fig. 1). Our method uses powerful signal processing algorithms to avoid any confusion that these irregularities may cause. Our algorithm does not intend to produce hyper-realistic 3D views. We aim to provide quite a good insight of the original appearance and organization of historical buildings at the time of the plan creation.

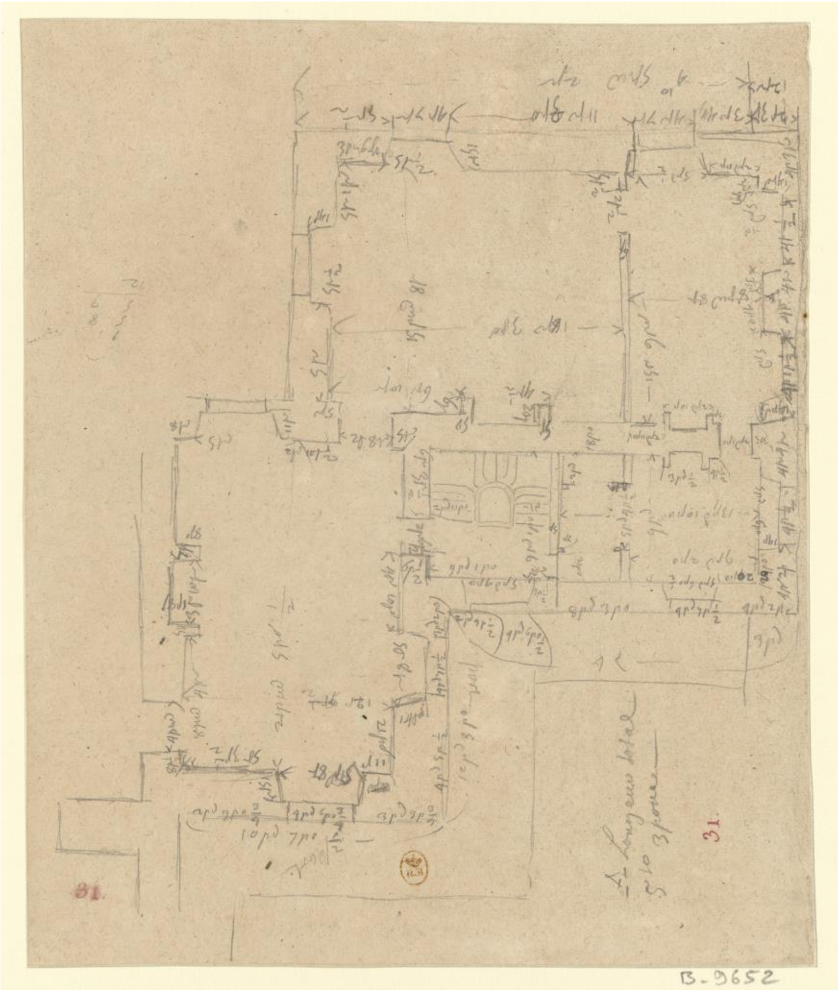


Fig. 1 An example of hand-drawn preliminary designed architectural plan

3. METHOD OF AUTOMATIC ARCHITECTURAL RESTITUTION

In this paper, we propose a method of the automatic architectural restitution of 3D geometry from old architectural plans and drawings. The first part of the process uses image processing algorithms, based on morphological mathematics, that extract relevant information from the floor plans, such as position and contour of load-bearing and dividing walls. Next, the walls are extruded along the axis of Euclidean space in order to generate the 3D model. The second part of process analyses elevations and cross sections in order to determine the accurate model height, localize openings and add textures.

3.1. 2D floor plan processing

As a first part of the method, we present 2D processing pipeline of a floor plan. After some pre-processing, such as denoising and an image resizing, we try to detect, localize and classify the building walls and stairs as essential structural elements that will help us extrude the primary 3D model.

3.1.1. Pre-processing

- *Image resizing and grey level conversion.* In order to reduce amount of information and increase the processing speed, the image dimension of architectural plan can be reduced by a factor r, by keeping the darkest pixel in each $r \times r$ vignette. As the plans are drawn with black pencil on almost white paper, the dark grey levels carry the useful information.

- *Denoising and binarization*. Firstly, a denoising processing is performed using the *Non Local Means* algorithm [18]. Next, we perform binarization process in order to detect and localize walls and stairs. Each pixel of binarized image I_b is computed as follows:

$$I_b(u,v) = \begin{cases} 0, & I(u,v) > med \\ 255, & I_{diff}(u,v) > s \cdot med_{diff} \\ 0, & otherwise \end{cases} \tag{1}$$

The median value of the grey level image I that is usually close to the background white colour of the paper, is represented by med ;

I_{diff} denotes an image that is created by computing the mean value of the absolute differences between the pixel's grey level and med for each pixel (u,v) in its 3×3 neighbourhood:

$$I_{diff}(u,v) = I(u,v) - med \tag{2}$$

The parameter s denotes a value of the fixed threshold and this value is experimentally defined.

The result of this process is the binarized image that shows well contrasting edges that will be easy to detect.

3.1.2. The building walls detection and localization

As a result of the binarization process, the walls are represented by dark strokes with different thicknesses. Thus, we use mathematical morphology algorithm to detect both main and dividing walls, only by tuning a threshold parameter. The detection is performed by iterating a unit ball morphological erosion process whereas each pixel, belonging to a convex component (wall), is labelled with its distance (Chebychev distance [19, 20]) to the nearest boarder of the component. Then the walls are selected in the distance image according to their thickness (Fig. 2).

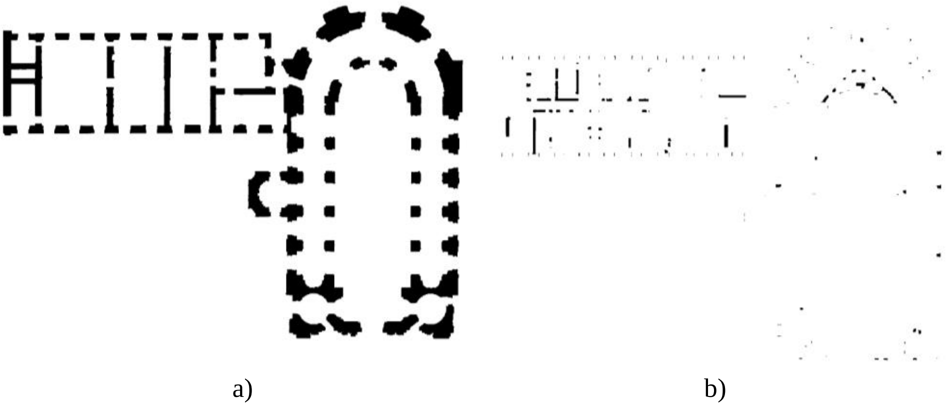


Fig. 2 Inverted image as a result of the walls detection from floor plans: main walls (a), dividing walls (b)

Next step is wall segmentation in which the contours of the detected walls are computed. The obtained contours define the edges of the final 3D model. We then compute straight segments from the detected edges and merge colinear neighbouring segments according to the following criteria:

CRITERIA — Let A is a segment, and B is the segment that is combined with A; the segments are merged if and only if the distance between the barycentre of the points of B and the line passing through A is less than a given threshold. We iterate the criteria until there is no more candidate segments.

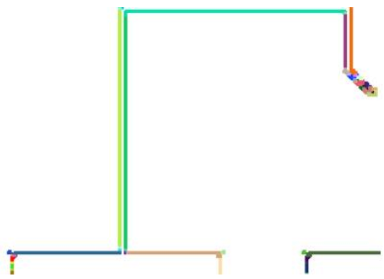


Fig. 3 Segments after fusion

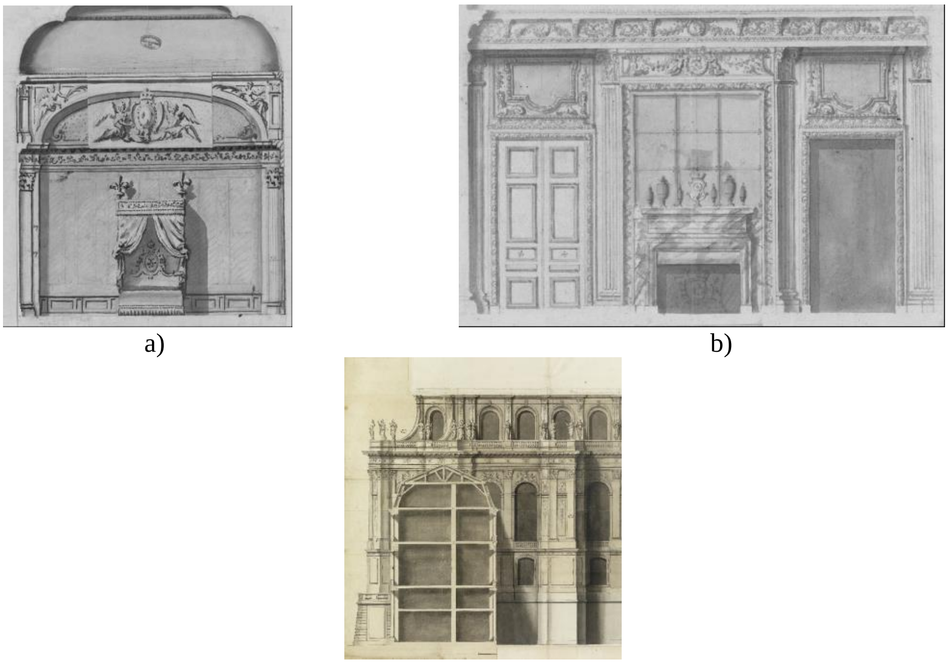
3.1.3. The staircases detection and localization

Due to the fact that old floor plans contain some of the unnormalized symbols that represent staircases, we use semi-automatic method for their detection. This method is less erroneous, it doesn`t need to be post processed, and thus, it makes the process of localization faster. It is consisted of detection and accurately localization of a rectangular area that the user designs around stairs.

The localization process works as follows: firstly, we detect the different convex components in the set stairs-walls of the floor plan by selecting a set of contiguous black pixels that are surrounded by white pixels and thus fully disconnected from the other components[1]. Secondly, we merge convex components that belong to the same implicit line segment. In order to compute the best line approximation for a given convex component, we use the well-known Tukey estimator [22]; each dash is represented by a convex component and its best line approximation (its angle with the horizontal axis). We store the X axis angles of all dashes in a circular histogram (each bin of the histogram represents a $5°$ deviation), then we merge all the dashes in the same bin of the histogram. As a result, the white regions are fully surrounded by the implicit lines joining the dashes; these white regions represent the stairs of the stairwell. If two adjacent convex components contain two common points, we state that they represent two stairs with a high probability. Thus, we keep all the pixels belonging to these components, which bounding box defines the bounding box of the staircase.

3.2. 3D restitution

By using information from the elevations and cross sections, next step of our algorithm is the third dimension calculation. Extruding the walls that have been detected and localized from the floor plan using previous information of a given height, a first preliminary 3D model is generated. Due to the real possibility that the walls height can be different for each room, the height of the walls is fixed arbitrary in the first step. However, this parameter will be tuned regarding to the analysis of the elevation images (Fig. 4).



a) b)

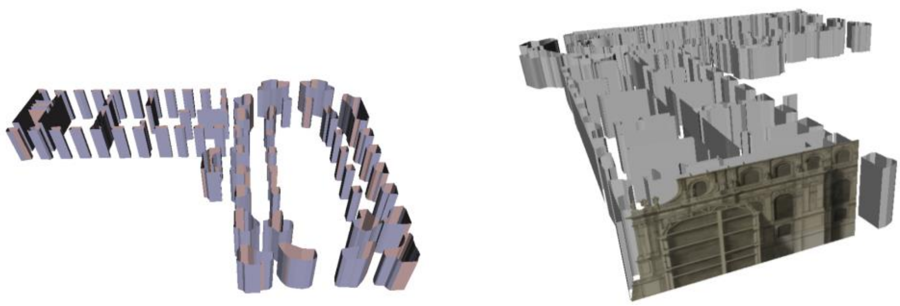
c)

Fig. 4 Original elevation images

[1] Please note that a dash is a convex component by itself.

3.2.1. Texturing the 3D model

After the first 3D extrusion, we use the elevation plans to refine the vertical 3D representation of the walls. At this point of process, each wall of the 3D model contains two adjacent triangles that form a rectangular face. After the manual selection of a wall on the primary 3D model, and selection of an approximately corresponding rectangular region at the elevation image, new vertical mesh is automatically constructed and the older wall of the primary model is replaced with new one. Elevation plan is used also for texturing the mesh. In order to compute the triangulation of the vertical faces of the 3D model, 2D triangulation of the elevation image is performed using the Delaunay scheme. Thus, all vertices of the polygon are obtained from the points of the selected region in the elevation plan. At the elevation image, flooding algorithm detects the contours of a key part of the image, by starting computation from the upper-left corner of the image to an arbitrary point that the user selects in the region. Finally, the boundary of the region is then triangulated applying mathematical morphology operators.



a) b)

Fig. 5 3D model generated using our algorithm: Preliminary extracted 3rd dimension of the building (a), and 3D model that is generated using one elevation wall (Fig. 4.c) (b)

The same procedure is performed for detection of the doors and windows position, as well as for the interior details definition.

4. GEOMETRIC DATA PROTECTION

Due to the very simple basic geometric structure of the automatically constructed model, a host vertex selection issue appears in the main step of the data hiding algorithm. Actually, more important is uniqueness of our model in comparison to digitalized statues, ornaments and all such “free-shape” digital representation. The first and crucial information of any architectural model is 2D position of coplanar vertices. On the other hand, coplanar vertices, as well as isolated vertices, are the most delicate part of every 3D model in terms of 3D data processing. Moreover, most of 3D processing algorithms include an optimization step that contains the decimation of such vertices.

Another significant issue is the low capacity of architectural models. In order to avoid this problem, we use selective selection of the host vertices. Thus, using the position of vertices that are obtained in the wall detection phase, we achieve stability of inserted data and also synchronization and detectability at the final, watermark retrieving step. Secondly, the triangulation of the wall texture (*3.2.1*) produces huge set of vertices, thus providing required capacity.

4.1. Inserting protection data into 3D geometry

Taking all previously mentioned in account, we suggest new watermarking method that include two parallel directions: first, dealing with important geometric features in order to stabile vertex selection [23] and second, using error correction codes for watermark message encoding and decoding, combining with Sparse QIM for watermark and authentication data protecting and embedding respectivelly [24]. Next block diagram represents flowchart of watermarking process that we suggest.

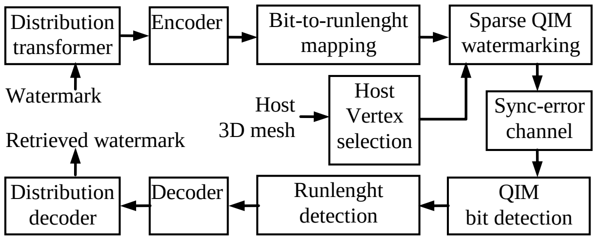


Fig. 6 Block diagram of the proposed protection system

4.1.1. Host vertices selection

Considering both methods for local curvature evaluation, the modified differential geometry method [23, 25] and the fitting quadrics method [26], we define several criteria for a geometric importance assessment. Results of our algorithm are two vectors: the vector of vertex stabilities arranged in a decreasing order, and the vector of corresponding indices. Hence, host vertices are selected and ordered with respect of decreasing stability [27].

4.1.2. Sparse QIM data embedding

We use $\mathbf{u}\in\{0,1\}^n$ and $\mathbf{x}\in\mathbf{R}^n$ as the watermark sequence and the cover sequence, respectively. The *embedder* combines the *n*-dimensional vectors **u** and **x** and produces the watermarked sequence $\mathbf{y}\in\mathbf{R}^n$. The difference **w=y-x** is referred to as the *watermarking displacement* signal. The distortion is typically defined as the simple Euclidian distance. The QIM operates independently on the elements *u* and *x* of the vectors **u** and **x**. To embed the bit $u\in\{0,1\}$, the QIM requires two uniform quantizers $\mathbf{Q}_0$ and $\mathbf{Q}_1$ defined as the mappings

$$Q_u(x) = \Delta\left[\frac{1}{\Delta}\left(x-(-1)^u\frac{\Delta}{4}\right)\right]+(-1)^u\frac{\Delta}{4} \tag{3}$$

where [ ] denotes the rounding operation, i.e. for a real *x*, [*x*] is the integer closest to *x*. Thus, the quantization level of the “nominal” quantizer $\Delta\,[x/\Delta]$ is moved up or down by $\Delta/4$ depending on the value of *u*. The watermark bit *u* dithers the input *x* by the amount $\pm\Delta/4$. The watermark bit *u* determines the selection of a quantizer, so that $y=\mathbf{Q}_u(x)$. Sparse QIM, spreads out the watermark bit over L elements of cover signal **x.** The cover sequence $\mathbf{x}_L$ of length is projected to a L-dimensional vector **p** of the unit norm, and the norm of the corresponding projection is quantized. The resulting watermarked vector $\mathbf{y}_L$ can be written as

$$\mathbf{y}_L = \mathbf{x}_L + (Q_u(\mathbf{x}_L^T\mathbf{p}) - \mathbf{x}_L^T\mathbf{p})\mathbf{p} \tag{4}$$

The detector projects the received watermarked cover vector $\mathbf{r}_L$ to **p** and recovers the embedded bit as

$$\hat{u} = \arg\min_{u\in\{0,1\}} \left\| \mathbf{r}_L^T\mathbf{p}_L - Q_u(\mathbf{r}_L^T\mathbf{p}_L) \right\|_2 . \tag{5}$$

5. CONCLUSION

We presented a method of data protection of 3D models that are obtained from automatic process of the geometric restitution, using old 2D architectural and artistic drawings. The first contribution of our research is the algorithm that includes several image processing steps, which are required in order to define walls, staircases and openings from the digitalized hand drowned architectural plans. The result of this step is detailed 3D model of the digitally processed historical building plans. The experimental confirmation of the algorithm accuracy is a 3D model of the Chateau de Versailles, which is descripted by old hand drawings, dating between the end of the XVII and the XIX century.

On the other hand, the key-achievement of our digital data protection system is new method of protecting the geometrical data using optimized adaptive Sparse Quantization Index Modulation (QIM) for embedding data bits into essential structure of the generated model. As a final result, we presented a secure authentication of the automatically restituted 3D model of the historically important artifact.

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