PATRECH2020 - II International Workshop on Pattern Recognition for Cultural Heritage

PatReCH 2020 - 2nd International Workshop on Pattern Recognition for Cultural Heritage

Workshop Description

PatReCH is a forum for scholars who study Pattern Recognition applications for Cultural Heritage valorization and preservation. Pattern recognition is rapidly contaminating new areas of our life day by day. On the other hand, the management of Cultural Heritage is increasingly in need of new solutions to document, manage and visit (even virtually) the enormous number of artifacts and information that come from the past. The contamination of these two worlds is now a reality and creates the bounds of the main topics of this workshop. Currently, Pattern Recognition technologies are already employed in the fields of Cultural Heritage preservation and exploitation. From these fields two main issues arise:

- the information contained in digital representations of physical objects like scanned documents, scanned artifacts, maps, digital music, etc. are not easy to exploit and advanced patter recognition analysis is required.
- at the same time, the production of digital material such as augmented reality, Cultural Heritage games, robotics applications, etc. need innovative techniques and methodologies.

The above issues are leading PR researchers to develop new methodologies and applications, which are able to analyze the available data and learn mathematical models to generate new ones in a smart way (for augmented reality, serious games, etc.). The aim of this workshop is to bring together many experts in this multidisciplinary subject that involves different skills and knowledge, which span from the study of the cultural heritage to the development of PR/AI techniques for cultural heritage analysis, reconstruction and understanding.

The second edition of the International Workshop on Pattern Recognition for Cultural Heritage was virtually held in Milan, Italy, in conjunction with the 25th International Conference on Pattern Recognition (ICPR 2020).

The format of the workshop included the talk of the invited speaker Davide Tanasi (University of the South Florida), followed by technical presentation in oral and poster format. This year we received 35 submissions for reviews from authors belonging to 19 distinct countries. After an accurate and thorough peer-review, we selected 25 papers for presentation at the workshop. The review process focused on the quality of the papers, their scientific novelty, and the impact for Cultural Heritage valorization. The acceptance of the papers was the results of two different reviews. All the high-quality papers were accepted, and the acceptance rate was 69%. The accepted manuscripts included very interesting PR applications for Cultural Heritage which interested the workshop's audience. Finally, we would like to thank the PatReCH Program Committee, whose members made the workshop possible with their rigorous and timely review process.

Organization

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Abstracting Stone Walls for Visualization and Analysis

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Abstract. An innovative abstraction technique to represent both mathematically and visually some geometric properties of the facing stones in a wall is presented. The technique has been developed within the W.A.L.(L) Project, an interdisciplinary effort to apply Machine Learning techniques to support and integrate archaeological research. More precisely the paper introduces an original way to "abstract" the complex and irregular 3D shapes of stones in a wall with suitable ellipsoids. A wall is first digitized into a unique 3D point cloud and it is successively segmented into the sub-meshes of its stones. Each stone mesh is then "summarized" by the inertial ellipsoid relative to the point cloud of its vertices. A wall is in this way turned into a "population" of ellipsoid shapes statistical properties of which may be processed with Machine Learning algorithms to identify typologies of the walls under study. The paper also reports two simple case studies to assess the effectiveness of the proposed approach.

Keywords: Data visualization · Data abstraction · Quantitative archaeology

1 Introduction

Integration of visual abstract representation with quantitative methods is today a well-established practice in Data Science. This paper proposes a simple, yet original technique to represent a stone wall. It has been developed within a CNR project aimed to apply methods of quantitative analysis to Prehistoric and Protohistoric architecture in Crete (Greece)[1].

[1] W.A.L.(L), *Wall-facing Automatic images identification Laboratory. A quantitative analysis method for the study of ancient architecture.* International Archaeological Joint Laboratories (2020–2021).

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Quantifying is in the nature of Archaeology and already since 50es statistics have entered this discipline that is familiar with tools such as spatial analysis, graphical representation, inference, cluster analysis, regression/correlation analysis [1, 2]. Quantitative methods are today firmly part of the archaeological discourse [3] up to the notion of Quantitative Archaeology [4] and the annual organisation by the CAA of an International Conference on Computer Applications and Quantitative Methods in Archaeology.

The growth of digital data in archaeology furtherly modified the "quantitative idiom" [5], allowing sophisticated data analysis. Advanced tools like unsupervised classification and Machine Learning, that until a few years ago were only available to statisticians, are now more widely adopted by archaeologists [6].

Nevertheless, archaeologists share a strong indication to develop methods sensitive to the unique problems of archaeological inference [1, 3, 7], in combination with primarily intuitive aspects of traditional archaeology.

On this base, the foreseen workflow of the W.A.L.(L) Project presented below led off from specific archaeological questions and from an on field analysis of the structures to be investigated (step 1).

	Steps	Problems of accuracy potentially affecting the results (to be evaluated and declared)
1)	Identification of architectural features estimated as peculiar and significant with relation to the investigated structures, to be mathematically analysed	
2)	Photogrammetric survey of the selected walls;	Resolution of the photographs (side dimension of pixels and number of pixels for cm²)
3)	Realization of a 3D photogrammetric model;	Resolution of the 3D model (number of photographs, number and edge size of the mesh triangles)
4)	Manual segmentation of the model (each stone is cut and mathematically analysed)	3D model resolution and operator-dependency factors
5)	Transformation of the model into an abstract mathematic model, composed by inertial ellipsoids	3D model resolution
6)	Elaboration of a conceptual model for a DB aimed to query the virtual models	
7)	Creation of a tool for the dialogue between a 3D visualizer and the DB.	

Fig. 1. Workflow of the W.A.L.(L) Project

The continuous intersection of the tasks respectively of archaeologists and computer scientists in the workflow means a strong confrontation between the different specialists of the research group - with their "foreign languages" - always relying on the consciousness that "meaning comes only from a body of theory" [5].

That is why, as an archaeologist, I feel intrigued by the experiment of abstraction of architecture we present in this paper and by being involved in an historical-content-free discourse, where doesn't matter if a wall is a Minoan or a Modern one, because of the abstract, axiomatic, formal language of mathematics is at the service of theoretical questions about which information is meaningful and how we can obtain it (F.B.).

The W.A.L.(L) Project foresees the integration of the geometric information discussed here within a relational DB specifically focused on the management of ancient architecture. In the last decade the digital analysis of architectural heritage has widely developed, bringing attention to the need to support the quantitative information with the qualitative ones, produced by interpretation of data acquired [8]. An important point is the treatment of 3D data and their connection with databases, as well as the semantic classification [9].

The correct interpretation and contextualization of the data is linked to a right conceptualization [10], which essential reference points are the CIDOC-CRM and, for our specific purpose, the recent extension CRMBA for the documentation of archaeological buildings [11]. The creation of a similar DB involves certain methodological key-issues: type and complexity of the objects, the strategic involvement of specialists, and the importance to normalize the terminology, using further existing vocabulary as the *Art and Architecture Thesaurus* (AAT) developed by the Getty Institute.

The added value of the DB for our project is the management and query of all the data related to masonries and wall facing stones, which are the fulcrum of the conceptual model. A complete data analysis will be made possible through the management of the background information (e.g. finding area, site, stratigraphic relationships, chronology, etc.), the peculiar features (e.g. material, typology, degree of working, petrographic analysis, etc.), as well as the previous documentation (excavation diaries, paper notebooks, photographs, drawings, maps, etc.), management of which involves the concept of archaeological legacy data and their reuse in a responsible way [12] (Ma.F.).

Researching and developing automated tools to assist the archaeological research is by now a relevant sub-field of Computer Graphics and Vision. [13] Although much theoretical work is yet to be done [14], “to abstract”, i.e. to draw away unnecessary information from the raw data to make understanding and conjecturing easier, is a common practice in many research fields. Principal Component Analysis is one of the most applied techniques to automatically achieve “abstraction” in an automated way. It has been applied to several high dimensional data to reduce complexity and to provide a parametric space for the classification of the observation (see for example [15]). The technique proposed here inscribes itself in this line of application, but to simpler 3D data as in [16]. In particular the paper proposes an original way to “abstract” the complex and irregular 3D shapes of stones in a wall with suitable ellipsoids. More precisely, a stone is first digitized into a 3D point cloud and then it is “summarized” by the inertial ellipsoid relative to such a cloud. The point cloud is considered as a rigid body and each vertex in the cloud is a material point of a unitary mass. Inertial ellipsoids, introduced in Mechanics by L. Poinsot in 1834 [17], are an established method of this discipline [18]. The substitution of the original stone shape with the abstract shape of an ellipsoid requires a relevant caveat: the proposed technique is not aimed to assess the static properties of a wall but only to illustrate and make more readable its layout. This is so because the point cloud of each stone refers only to the wall facing, i.e. to the “exposed” part of it.

The visual representation of the wall as an aggregate of ellipsoids is a valuable tool to more clearly read the layout of the wall and may help the expert to gain insights, formulate hypotheses about construction habits, dating or comparisons with other walls. More: the parameters of the inertial ellipsoids (size and orientation) summarize well the high/middle scale geometric properties of stones. A wall may hence be treated as a “population” made by such ellipsoids and its statistical properties may be used to identify typologies of the walls under study. Analysis of these data with Machine Learning algorithms will be considered in further studies.

This paper substantiates the above claims by reporting the results obtained with two case studies of walls from Donnafugata (from about 1900 A.D.) and Mongialino (from about 1500 A.D.) in Sicily. The paper is organized as follows: first, the pipeline from the image acquisition to the 3d model construction, to the computation of the inertial ellipsoids is described. In a successive section the results from the application of the method to two case studies are reported. In the conclusion the proposed technique is framed within a more ambitious program about the use of Data Science technique in archaeological studies (G.G.).

2 The Proposed Technique

The technique presented in this paper is part of a more general processing pipeline that could be summarized as follows (see Fig. 1):

Step 1. Photogrammetric survey of the selected walls;
Step 2. Realization of a 3D photogrammetric model of a whole wall section;
Step 3. Manual segmentation of the 3D model into separate sub-meshes for each stone of the wall;
Step 4. Transformation of stone sub-meshes into corresponding inertial ellipsoid;
Step 5. Data mining over the DB of the intrinsic (size) and extrinsic (orientation) geometric properties of the ellipsoids;

This Section offers an overview of the whole process with greater focus on Step 4 and Step 5.

Data Collection and 3D Reconstruction. The technique starts with a photographic survey of the wall fragment under study. 3D reconstruction may be done with off-the-shelf tools. In our experiments Meshroom from AliceVision has been used [19]. A highly detailed model is obtained in this way (average edge mesh in 0.2–0.8 cm range).

Cleaning and Decimating Data. The reconstructed wall mesh is imported into Blender 2.9.1 3D software [20] to be cleaned and aligned to a global reference. For the scope of this paper, only moderate spatial resolution is needed; for this reason the mesh is decimated to a resolution of average edge mesh in 0.8–1.5 cm range.

Segmentation into Stone Sub-meshes. The lighter mesh obtained insofar is segmented into a collection of sub-meshes, one for each visible stone of the wall. No available automatic technique can, up today, produce a reliable segmentation of the stones due to the large irregularity of their shape and layout: a human operator is needed at this step. Intra- and inter-operator variability have been checked and no significant differences have been found. A wall is now a collection of sub-meshes. The mortar is not considered.

Analysis of Stone Sub-meshes. Further abstraction is obtained computing numerical information for each sub-mesh. The computations are done within Blender with a Python script. Vertices are considered as material points of unitary mass, and their ensemble is assumed to be a rigid body. The following information are at first computed:

- Coordinates of the center mass of the sub-mesh M_x, M_y, M_z.
- Variance of the vertex coordinates of the sub-mesh around the center mass: V_x, V_y, V_z.
- Mean normal of the faces of the sub-mesh $N_m = (n_{m,x}, n_{m,y}, n_{m,z})$.
- Variance of the normal of the faces of the sub-mesh: V_{nx}, V_{ny}, V_{nz}.
- Inertial symmetric 3x3 tensor T of each sub-mesh.
- Eigenvalues Ev_x, Ev_y, Ev_z and eigenvectors rotation matrix *Rot* of T.

Visualization of Inertial Ellipsoids. A new object collection is created in the Blender scene including a 3D ellipsoid for each stone sub-mesh. The lengths of the axes of each ellipsoid are proportional respectively to ${Ev_x}^{-1/2}$, ${Ev_y}^{-1/2}$, ${Ev_z}^{-1/2}$. Each ellipsoid is centered at its (M_x, M_y, M_z) and rotated by *Rot*.

The material of each ellipsoid may be assigned random or may color-code other information. For sake of demonstration of this possibility the $n_{m,y}$ indicator has been color coded in the experiments reported below, other choices are of course possible. Eventually the ellipsoidal simplification of the wall is presented to the expert and can be used for visual inspection and reasoning.

Statistical Data exploration. All the information gathered insofar is saved into a .csv file suitable for further statistical analysis. The analysis may be oriented to two main tasks: a) classification of stones into several categories; b) characterization of the wall through the distribution of the indicators of its stone population.

Both directions are promising and research in this direction is still in progress. As for single stone classification it should be noted that, since the processing is done on a middle/low resolution model, lack of finer details makes this task difficult. The initial results about the wall characterization are, on the other hand, promising.

(G.G., Mi.F., P.M.R.).

3 Two Case Studies

The two selected case studies are one wall fragment near to the Donnafugata Castle and one wall fragment inside the Mongialino Castle. Both walls have facing sizes of about 1.2×1.6 m. The first is a typical wall of the Ragusa district in Sicily dated about early 1900 A.D. The second one has been built about 1600 A.D. (Fig. 2).

Resulting abstractions with inertial ellipsoids are shown in Fig. 3. Both gray colored and color-coded ellipsoids are shown. The color coding refers, for sake of demonstration, to the $n_{m,y}$ indicator, i.e. the magnitude of the normal mean facing the observer.

The abstract visual representations capture the geometric layout of the walls and enhance the structural differences between the two walls, proving that the proposed method may offer a great help to the expert in formulating hypotheses and assessing properties.

Besides providing visual help the proposed method produces valuable numerical data for statistical analysis. Although the research about this issue is currently in progress the two case studies reported here offer some evidence of the potential use of the proposed

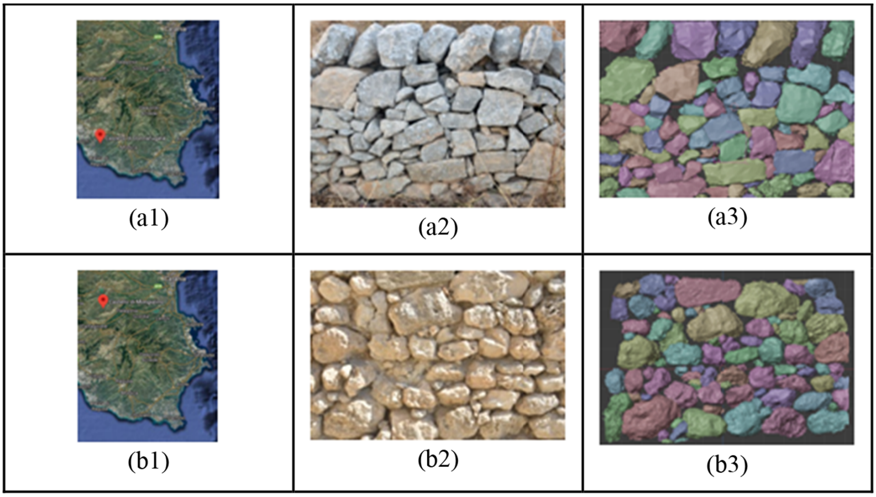

Fig. 2. (a1), (b1) Donnafugata and Mongialino locations; (a2), (b2) photos of the two walls; (a3), (b3) the segmented walls in false random colors. (Color figure online)

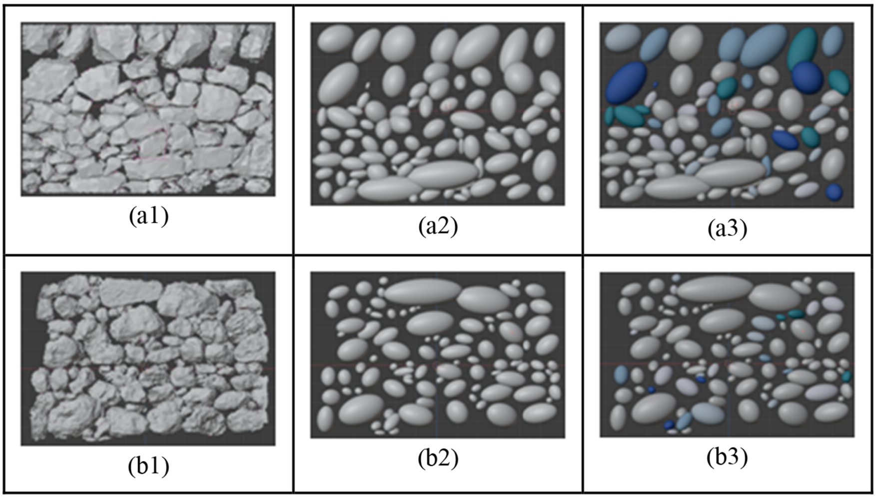

Fig. 3. (a1), (b1) 3D models of the two walls; (a2), (b2) inertial ellipsoids representation; (a3), (b3) color coded ellipsoid: degree of blue means greater values of the $n_{m,y}$ indicator. (Color figure online)

approach. In particular Fig. 4 shows the distribution over the two populations of the indicators $V = V_x{*}V_y{*}V_z$, $R = V_{Nx}{*}V_{ny}{*}V_{nz}$ and of the $n_{m,y}$ indicator. The V variable is a good indicator of the size of the corresponding stone. Similarly the R variable provides a rough estimate for the degree of roughness of the stone. The indicator finally provides an approximate estimate of the "overhanging" degree of the triangular faces in the corresponding mesh.

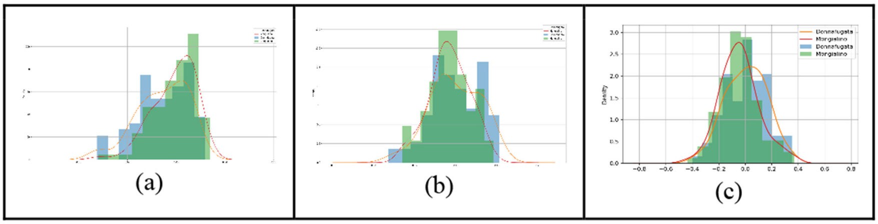

Fig. 4. (a) Histogram and density plot of the indicator $V = V_x * V_y * V_z$; bimodality of Donnafugata stones (cyan) vs unimodality of Mongialino stones (green) is manifest; (b) histogram and density plot of the indicator $R = V_{nx} * V_{ny} * V_{nz}$; (c) histogram and density plot of the indicator $n_{m,y}$ shows the more uniform layout of Mongialino stones vs Donnafugata stones. (Color figure online)

The histograms visually show some difference between distributions of the above indicators over the two populations under study. Chi square test has proven significant only for the indicators V ($p < 0.01$) and R ($p < 0.01$).

A visually evident difference between the two distributions of both the variables V and R is the bi-modality of the Donnafugata data versus the unimodality of the other sample. This could be read in qualitative terms as an evidence that while in Donnafugata stones are of two classes (larger and more polished and smaller rougher ones) the wall fragment from Mongialino is made of more homogeneous stones in size and roughness. (G.G., Mi.F., P.M.R.).

4 Conclusions and Future Work

The method presented in this paper is a promising experiment at an early stage of the workflow foreseen by the W.A.L.(L) Project. While abstraction allows to obtain and visualize information about the essential properties of the stones in the wall facings (i.e. dimensions and orientation), further features have to be taken into account under a quantitative perspective (shape; coursing and positioning; finishing of the stones). The use of photogrammetric models purposely realized to fit this goal constitute a strength from the point of view of innovation in ancient architecture analysis, but also entail several challenges, from issues of accuracy, to the resolution and manageability of the 3D models, to specific problems posed by Iron Age architecture, highly irregular and therefore poorly predictive (F.B.).

Further work will include semi-automatic assistance for stone segmentation, the extraction and integration of further features and their integration in the DB discussed in the Introduction and the application of Machine Learning methods to assist the specialist in the archaeological issues of interest (G.G.).

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