Laura Carlevaris, Graziano Mario Valenti

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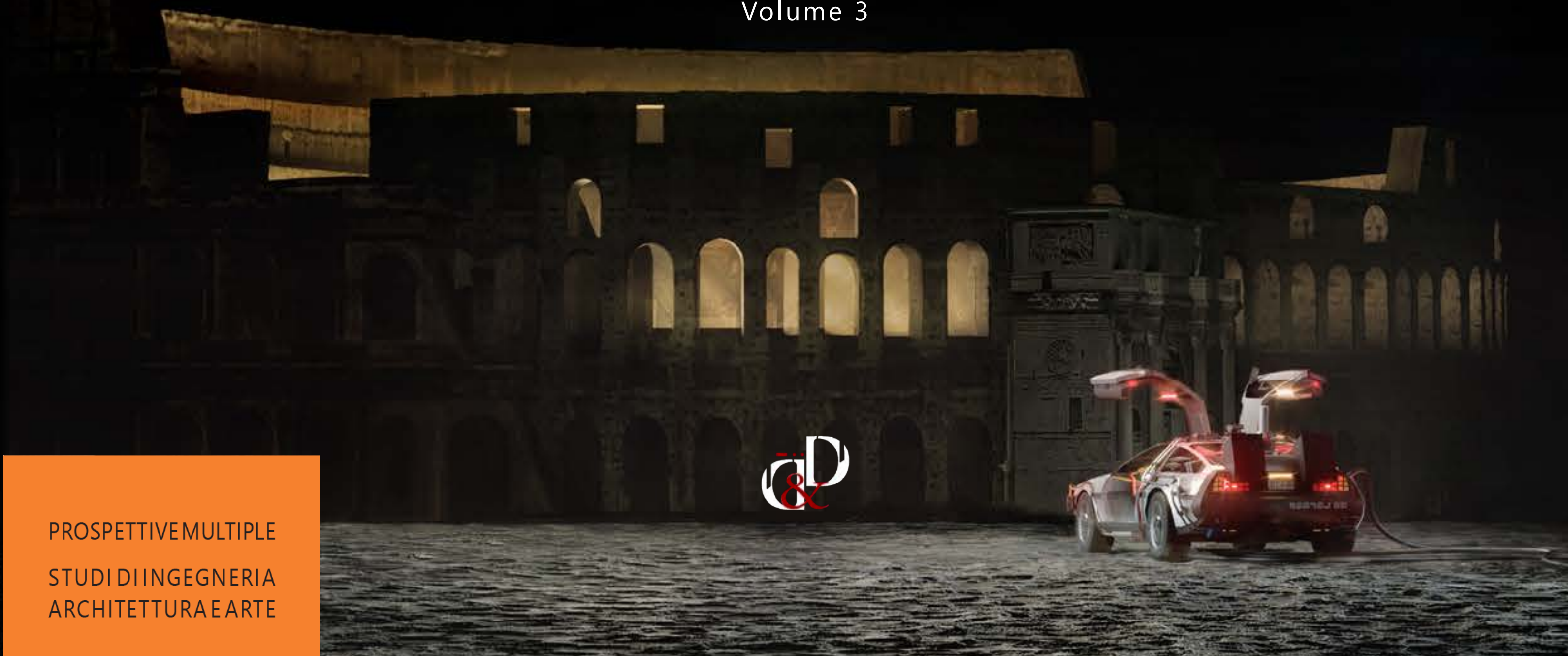
Digital & Documentation

Reading and Communicating Cultural Heritage

Volume 3



PROSPETTIVE MULTIPLE

STUDI DI INGEGNERIA ARCHITETTURA E ARTE

Laura Carlevaris, Graziano Mario Valenti

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Digital & Documentation

Reading and Communicating Cultural Heritage

Volume 3

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The volume consists of a collection of contributions from the seminar *Digital & Documentation. Reading and Communicating Cultural Heritage*, realised on online platform on December 4th, 2020. The event, organized by Department of History, Representation and Restoration of Architecture, Sapienza University of Rome, promotes the themes of digital modeling and virtual environments applied to the documentation of the tangible, intangible and natural Cultural Heritage. The event has provided the contribution of external experts who are engaged in the management and conservation of the most important Italian cultural assets.
The scientific responsible for the organization of the event is Prof. Graziano Mario Valenti, Sapienza University of Rome.

This publication is made with the contribution of DSDRA, Department of History, Representation and Restoration of Architecture of Sapienza University of Rome.

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Department of History, Representation
and Restoration of Architecture
Sapienza Università di Roma

The event *Digital & Documentation - 2020* has seen the participation of professors, researchers, scholars and private Institutions

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dell'Università
e della Ricerca

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del Colosseo

Gallerie Nazionali
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e Palazzo Corsini

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Università Iuav
di Venezia

The event is promoted by UID (Unione Italiana per il Disegno)

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Valeria Cera, architect and Ph.D. in Sustainable Technologies, Survey and Representation of Architecture and Environment at the University of Naples Federico II. Post-Doc researcher at the Department of Architecture of Naples in the discipline of representation, she is a fixed-term researcher at the same University for the SSD ICAR / 17. She collaborates at the activities of the Interdepartmental Research Center UrbanEco and of DIARC Department of Architecture and she is involved in the initiatives of CISI Sino Italian Interuniversity Consortium. Her studies focus on architectural, urban and archaeological surveying techniques, on the semantic annotation systems of digital models, on the methodologies of representation and communication of historical heritage also through Artificial Intelligence systems. She participates in several international conferences on these issues as a speaker and publishes in scientific journals and monographs.

1.

05 OPTIMIZATION PROCESSES OF POLYGONAL MODELS FOR MANAGEMENT IN WEB-BASED INFORMATION SYSTEMS

VALERIA CERA

Abstract

This paper is part of the scientific debate concerning the definition of protocols for the structuring of digital models, rendering examples of the architectural heritage, within web-based fruition and query platforms. In particular, the research presents the codification of a methodological proposal together with the description of the various operations, carried out on an exemplary case study.

The described processes deal with the phases of capturing the geometric and colorimetric information of the case study through reality-based survey techniques and analyse the subsequent structuring of digital replication carried out by automatic decimation algorithms, retopologization processes and texture baking.

The aim of the study is to provide a possible protocol, in line with the approaches described in literature and widely validated, to be applied in heritage digitization projects and construction of online platforms for the analysis and optimized management of digital twins.

Il contributo si inserisce nel dibattito scientifico concernente la definizione di protocolli di strutturazione di modelli digitali, restitutivi di esemplificazioni del patrimonio architettonico, all’interno di piattaforme di fruizione e interrogazione *web-based*. In particolare, la ricerca presenta la codifica di una proposta metodologica di cui sono descritte le diverse operazioni, condotte su un caso studio esemplificativo.

I processi descritti affrontano le fasi di acquisizione delle informazioni geometriche e colorimetriche del caso studio tramite tecniche di rilievo *reality-based* ed esaminano le successive attività di strutturazione della replica digitale condotte con algoritmi di decimazione automatica, processi di retopologizzazione e *texture baking*.

L’obiettivo dello studio è fornire un possibile protocollo, in linea con gli approcci illustrati in letteratura e diffusamente validato, da applicare in progetti di digitalizzazione del patrimonio e allestimento di piattaforme *online* per l’analisi e gestione ottimizzata dei gemelli digitali.

Introduction

The technological improvement of sensors for the digitization of architectural artifacts together with the fast evolution of ICT applied to cultural heritage have determined an increasingly widespread trend towards the design and implementation of digital information systems in order to variously interrogate and use the constructed models and the documentary apparatus linked to them [Galasso et al. 2021; Luigini et al. 2019].

However, if on one hand the construction of web-based platforms involves theoretical issues underlying the definition of rigorous and appropriate strategies for the correct structuring of the information base, on the other hand it implies the formulation of adequate IT processes for manipulating the digital model in order not to invalidate its online consultation and use [Banfi and Bolognesi 2021; Perticarini et al. 2020; Sànchez Allegue et al. 2018].

The survey tools for data capture and their modeling techniques return digital representations whose complexity, measured by the number of detail polygons that can be produced, grows significantly faster than the ability of graphics hardware to manipulate them interactively as well as the possibility of information systems to archive and manage them. Pushing geometric acquisition towards indiscriminate levels of detail and accuracy is pointless, if it produces models that are practically unmanageable by programs, platforms and the web due to the significant number of surfaces and vertices that constitute them. The answer to the problem given by the polygon mesh simplification algorithms is not enough to solve the question in case the mesh streamlining procedure can involve a loss of detail and/or a significant modification of the topology in areas where, on the contrary, is required more specification. In this way, the obtained digital replicas could have actually lost the identity character of the real object to which they refer both in terms of geometric coherence and fidelity and aesthetic quality of visual perception.

Therefore, in order to gain searchable digital 3D representations which are at the same time, manageable from the point of view of the IT infrastructure, always keeping the focus on architectural precision, accuracy and reliability, they must be subjected to specific geometry reduction processes such as not to compromise visual fidelity and consistent understanding of information content.

In line with this concept, the paper presents the coding of a structuring protocol of digital models, rendering examples of the architectural heritage, within web-based fruition and query platforms.

The proposed methodology comes from the approach already defined within the PRIN CHROME[1] research project and that has been applied to the project actions of the PON FESR SCOPERTA[2] [Cera 2019; Cera et al. 2018]. The protocol was subsequently improved on the occasion of the study activities relating to the scientific collaboration established between the Urban / Eco Interdepartmental Research Center and the Diocese of Teggiano-Policastro[3] and it is explained below in its various operations, carried out on a case study selected for demonstrative purpose but it is repeatable for other examples of historical construction.

Specifically, the processes described tackle the phases of capturing the geometric and colorimetric information of the case study through reality-based survey techniques and analyze the subsequent structuring of digital replication carried out with automatic decimation algorithms, retopologization processes and texture baking, suitably defined for the querying of the model in an online information system.

Reality-based data acquisition

The process of structuring the digital model is here presented applied to the pulpit of the Church of San Michele Arcangelo in Padula.

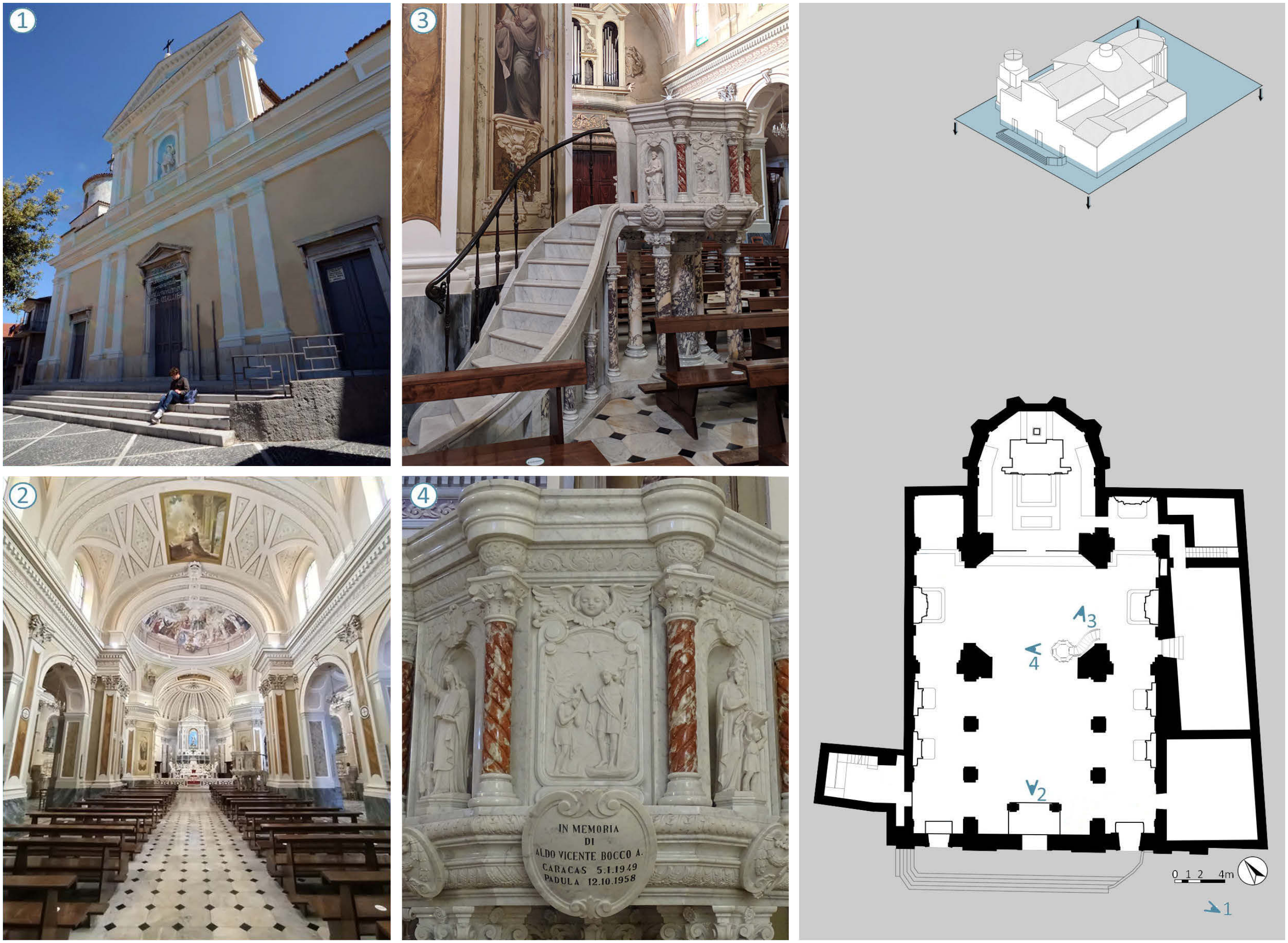


Fig. 1 - Church of San Michele in Padula. Photographic overview.

The first phase of the process focuses on the capture of geometric and colorimetric data, from which it will be possible to build a digital model, representative of the object of study, systematized according to its suitable use in web-based platforms.
The pulpit has significant dimensions: 3.30 m x 2.40 m overall dimensions on the horizontal plane, 2.84 m total height, a depth (of the raised octagonal platform) equal to 1.45 m. It is located near the transept, close to the first separation pillar, towards the altar, between the central nave and the right-side nave of the cathedral of Padula (fig. 1).
Typical expression of the Baroque language, it is entirely made of different colored marbles and it develops on two orders. The first, the lower one, consists of 5 Corinthian columns in black and white marble, designed to support the second level. This level is made by an entablature with sculpted marble shields, and it is surmounted by an octagonal balustrade in white marble composed of bas-reliefs of characters and scenes of Christianity contained in six red and white twisted columns. The two orders are linked by a sinuous 10 steps staircase made of marble.
The pulpit was captured through the acquisition of 7 scans with phase modulation TLS, a tool chosen to meet the contextual need for surveying the entire spatiality of the church as well as for the level of accuracy and geometric precision achievable by using this instrumentation, coherent with the aims of the survey. The scans were carried out at a rather close distance between the captured range maps - of a maximum of 1.5 meters - in relation to the distributive characteristics of the church that hosts it and to its own dimensions. For the same reasons, the stations were distributed along the 3 free sides of the pulpit, since the right side of the pulpit was leaning against one of the side pillars of the central nave and planned with the aim of reproducing the entire shape with fewer holes and possible shade areas, avoiding the tangency of the surfaces. In particular, 2 scans were positioned to frame the lateral ends placed at eye level, 2 scans in correspondence with the empty compartments between the spiral columns supporting the mezzanine, placed at a lower level (approximately 0.90 m), 2 scans in a central position to frame the main elevation of the pulpit, placed at an elevated height (2.05 m) and 1 last station in a central position, at eye level but at a greater distance from the object of about 3.5 m (fig. 2).
Being a plastic element, rich in sculpted elements, an average resolution of 6 mm was chosen at a distance of 10 m and an accuracy of 4x, thus obtaining a thickening step of the range maps of approximately 1 mm at 1.5 m.
To limit contacts with the object of study and the environment in which it is housed, no targets, either spherical or flat, were positioned, leaving the identification of natural homologous points to the alignment process, to be traced directly on the architecture. For this purpose, the shots were planned in order to ensure the framing and registration of as many specific geometric elements as possible in order to simplify the subsequent alignment phase of the scans. Choosing not to use targets also responded to the desire of obtaining a 'clean' representation, without extraneous elements that could possibly occlude some specific portions of the texture surface.

Data processing: from point cloud to textured mesh

The alignment of the individual scans was performed with the instrument's proprietary processing and recording software to ensure the most correct rigid roto-translation procedure between the point clouds with deviation values as low as possible.
Lacking targets in the scene, the software allowed the recognition of homologous points to be aligned, through best-fitting procedures of geometric primitives such as planes, edges, and faces.

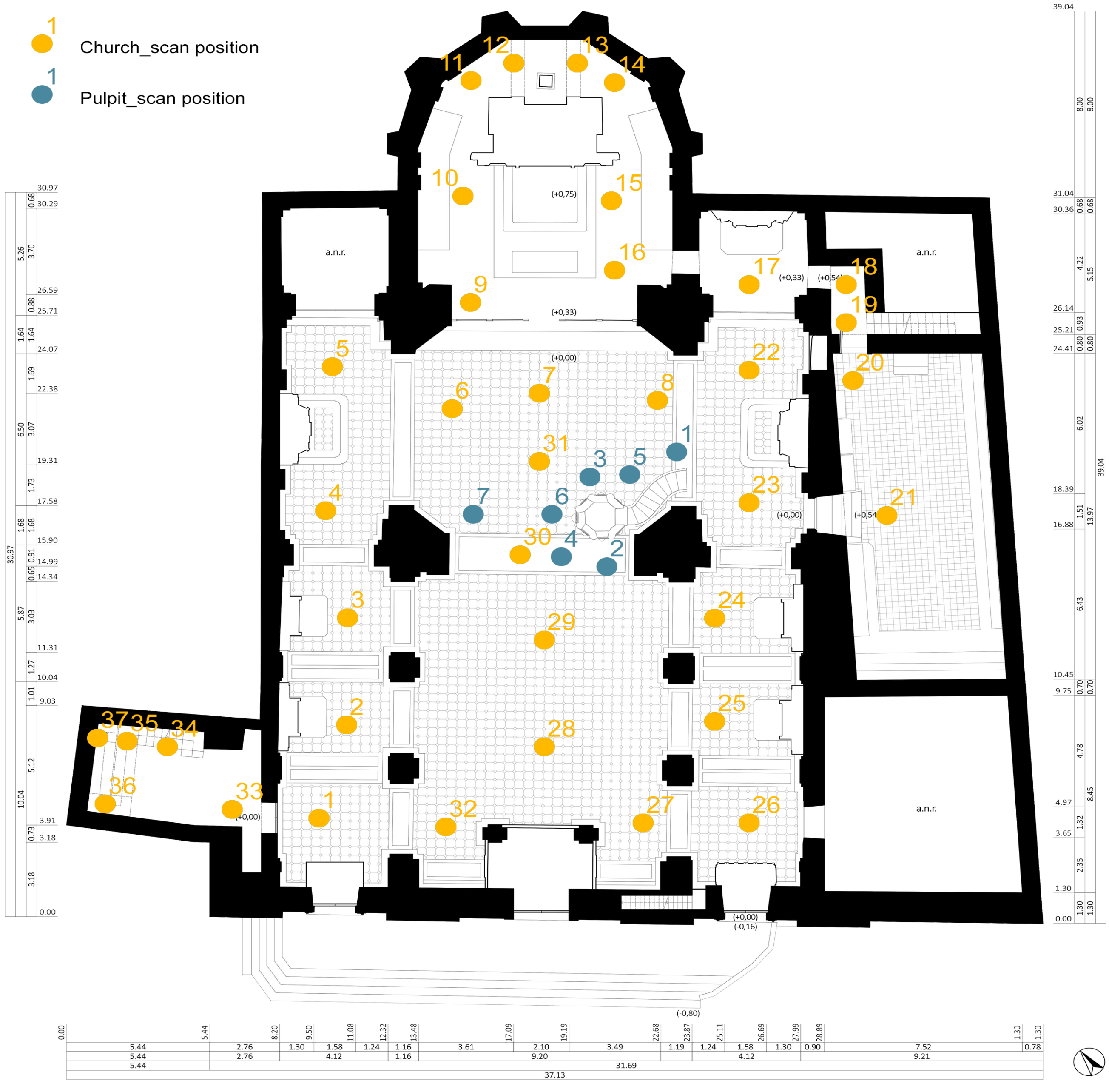


Fig. 2 - Reality-based data acquisition. Schematic drawing of scans positions.

Having recognized at least 3 primitive elements present in the overlapping area between the scans, the 3D positions of the elements to be aligned were identified by the software, used to assign the initial rotation and translation to the scans with respect to the chosen reference system. The elements placed at more than 25 m, were excluded from the alignment procedure, unable to provide accurate position information. However, having acquired large portions of the church that houses the pulpit as well, these areas have provided a wealth of useful elements for the reciprocal roto-translation of the scans.

The automatic procedure did not require any manual integration of further homologous points where no alignment errors occurred. The tension recorded between the different primitive elements present on the individual scans appears to be of the order of a millimeter.

The resulting recorded cloud was transformed, in a second step, into a single polygonal surface through the *RealityCapture* software. The scans recorded were, therefore, imported in compatible .ptx format, maintaining their spatial location.

Subjected the scans to a verification of the alignment process for the automatic computation of their position and orientation in the scene, the polygonal model was derived from the calculation of depth maps. Starting from the extraction of tie points from the different scan clouds, exported with reflectance information, the triangular mesh was calculated by imposing exactly the points captured with the laser scanner as the vertices of the polygons. The density of the cloud was filtered by requiring that points with an intensity lower than 0.03 to be discarded since they were considered inaccurate. Starting from the lightened data, the polygonal surface was generated in which no topological inconsistencies were highlighted. The result is a representation that, from the geo-metric point of view, is quite precise and accurate, consisting of 57,476,728 polygons and 28,759,871 vertices.

To provide the polygonal model with a considerable degree of visual realism, the texturing operation was carried out using the 'multi-band' calculation method and special frames captured with a Canon EOS1300D SLR.

Mesh simplification and management process: decimation, retopology and texture baking

Once the texturized digital model has been obtained, the formalized protocol works on the cleaning, decimation and re-texturing of the data obtained, according to their adequate use in an interrogation and fruition platform.

The simplification procedure was performed in the opensource application *Meshlab* where the reduction of the number of polygons of the model was preceded by a series of cleaning operations of the digital representation in order to optimize the decimation.

Exported from *RealityCapture* in .ply format, the pulpit mesh was subjected to the following processes in *Meshlab*:

(i) Remove Duplicate Faces;
(ii) Remove Duplicate Vertices;
(iii) Remove Unreferenced Vertices.

The operations identified and therefore eliminated fifty duplicate faces. The subsequent simplification was carried out by pursuing the geometric optimization of the model through a vertex merging algorithm, the Quadric Edge Collapse Decimation. This was preferred because it represents a good compromise between strength, speed and final rendering.

The number of faces to be obtained with the simplification was previously decided, and set l to 2M[4]. For this reason, the model reduction percentage was set to 0. To approximate, for the original form, in the simplified model, a quality threshold of 1 was set, in a range [0,1] in order to compute only well-shaped triangles and the faces with one maximum penalty with a proportional penalty of the shape, lower than the established value. At the same time, the control of the iterative procedure involved

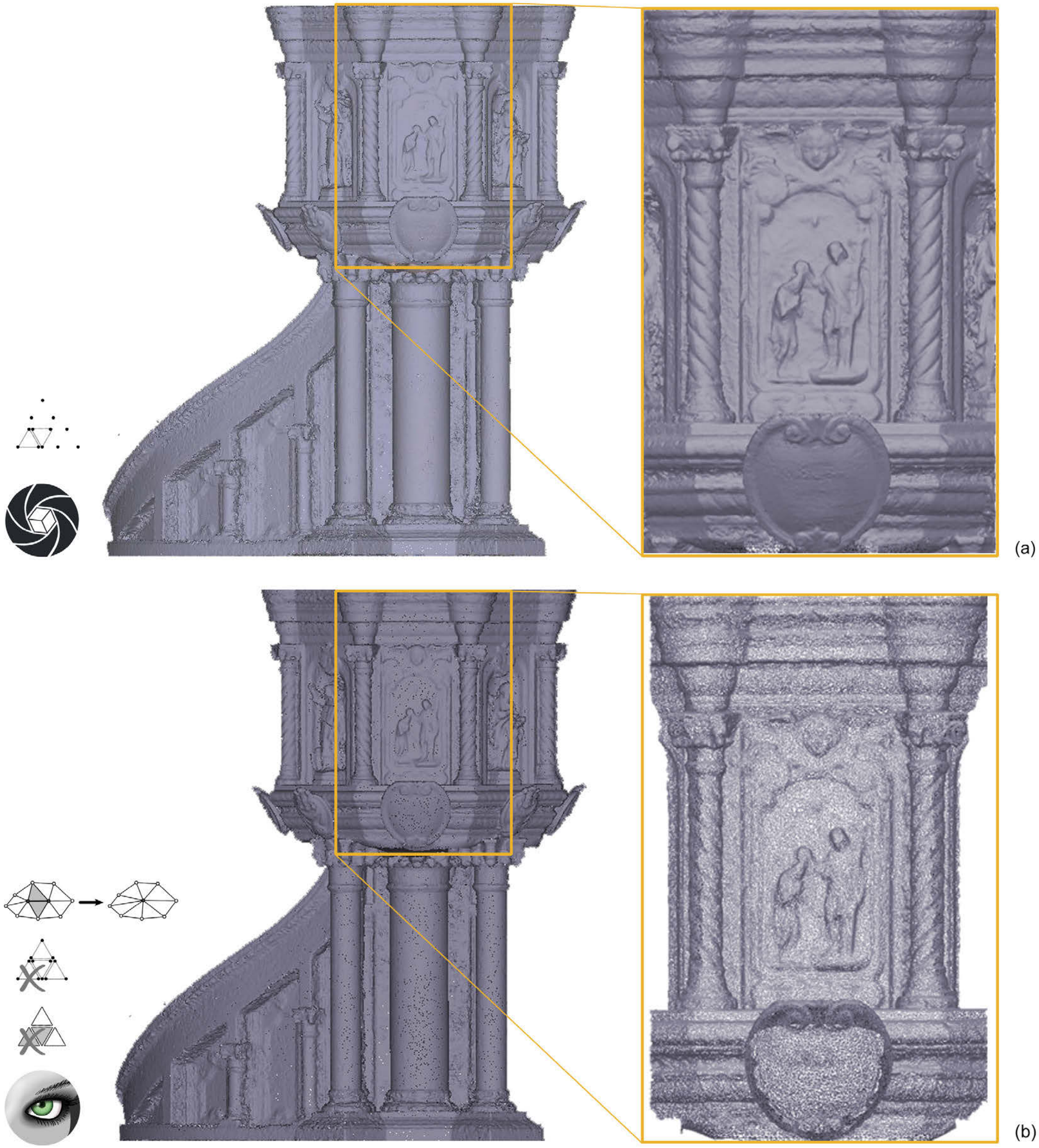
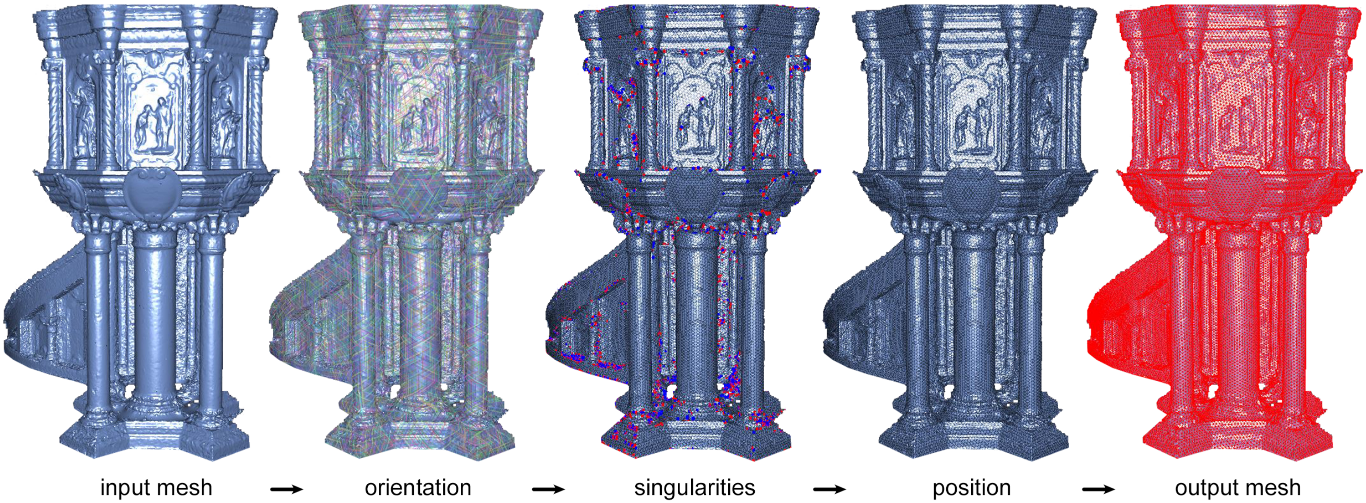


Fig. 3 - Polygonal model decimation process.

compliance with the edges, the normals, the topology, and the optimization of the position of the simplified vertices.
Starting from the high poly mesh, of 28,759,871 vertices and 57,476,678 triangles (fig. 3a), a simplified – low poly mesh – with 1,006,109 vertices and 2,000,000 polygons (fig. 3b) was obtained, imposing a weight for the importance of the edges during the process equal to 1, in an interval [1.0], corresponding to the maximum relevance. An additional clean-up of the reduced model was performed to ensure the removal of unreferenced vertices and triangles with a penalizing shape.
To facilitate the subsequent mesh management in online information systems, a re-topology of the 3D representation was carried out. In the Instant Meshes opensource application, the model was further decimated bringing the number of triangles to 71.67k and their position and orientation was perfected (figs. 4, 5).
In order to not compromise the rendering of the model and maintain geometric fidelity even in the visualization task, following the reduction operation carried out, the detail was recovered through a texture baking process.
With the Blender software, the normal map resulting from the comparison between the high poly mesh and the low poly mesh was calculated. Following the same approach, the color information and ambient occlusion data were processed using the high polygonal content mesh. In this way, even if some geometric data were lost during decimation, the simulated light behavior, in the display and rendering engines, accounts for the effect of the removed details. These maps are in fact projected on the simplified areas of the mesh, reproducing the polygonal complexity of the same regardless of their level of surface specification (fig. 6a). The technique therefore allows, starting from a very complex model, to be projected on one another, used as a base but with a lower number of polygons. The process thus makes the fruition fluid and quick, by virtue of the geometric simplification carried out, while preserving at the same time the realism and coherence of the perception both of the digital



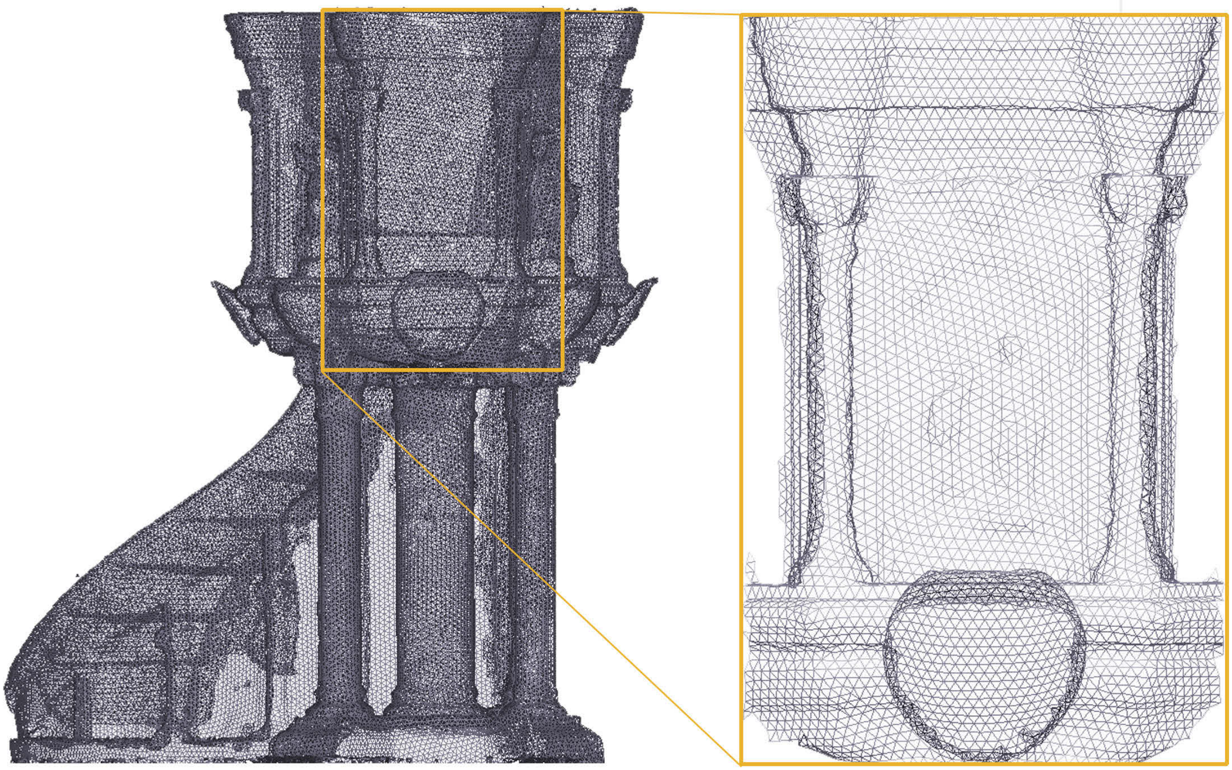


Fig. 4 - Retopology and optimization process.

Fig. 5 - Final decimated and retopologized mesh.

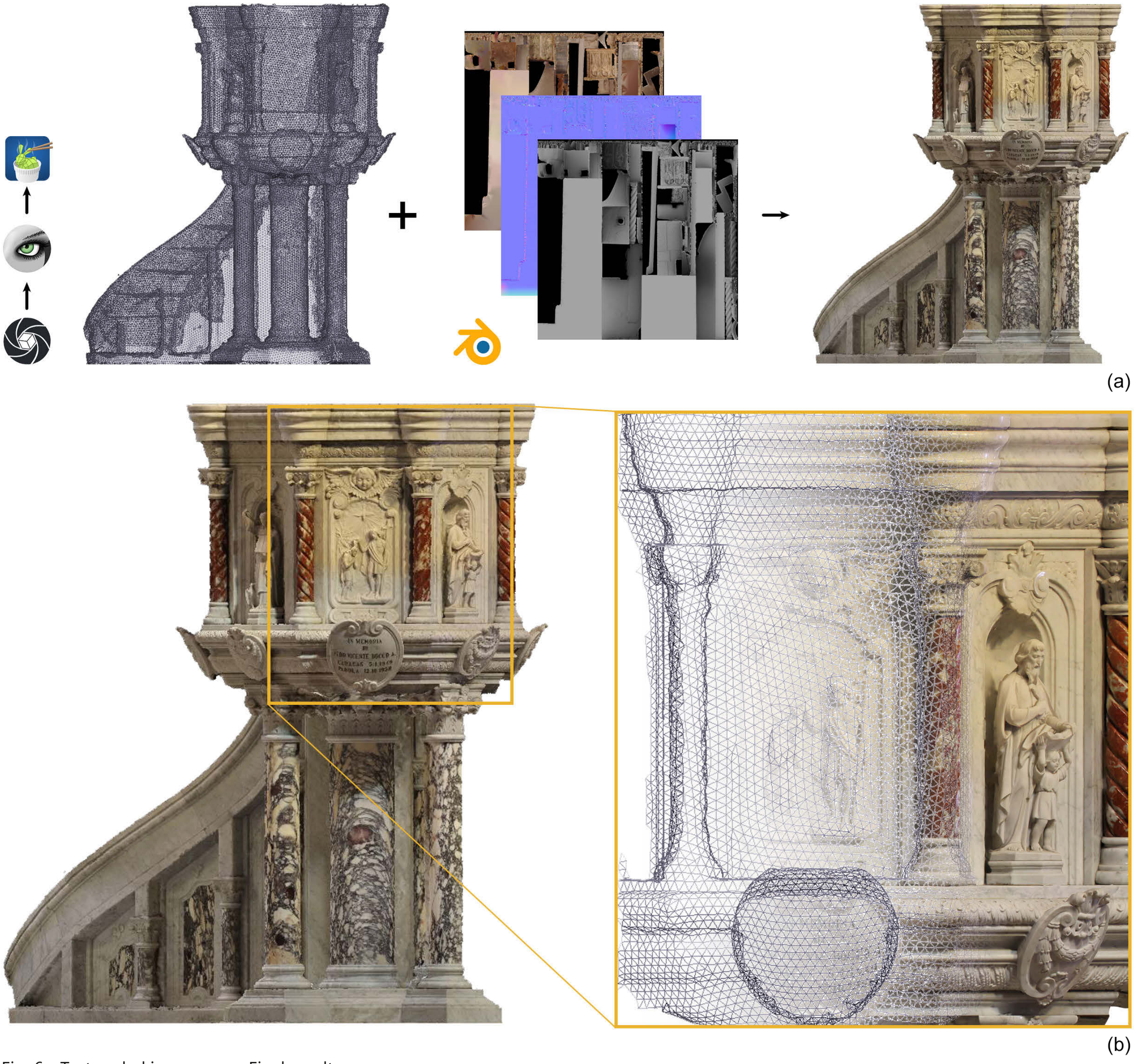


Fig. 6 - Texture baking process. Final result.

representation itself and of the informative contents (think, for example, of the aesthetic quality of surfaces in terms of texture, color and degradation) associated with it (fig. 6b).

Conclusion

The widespread digital literacy of the community and the increasingly massive diffusion of ICT technologies in the field of digital representation of architectural artifacts offer researchers and professionals a very wide range of possibilities in which the compromise between the issues of computer management of 3D models and scientific aspects of the organization of information resources represent a critical node of the question.

In this context, the paper aims to provide a possible operational response by explaining a procedure for structuring digital models gained from reality-based acquisitions of examples of the architectural heritage to be applied in projects for the creation of web-based management information systems. Aware of the vastness of simplification algorithms and applications designed to recover topological inconsistencies of polygonal meshes, the research aims to highlight a possible approach to the management of 3D representations within digital platforms in which the focus is on preserving, above all, the informative coherence of the model, both from a purely geometric to a formal, and perceptive point of view, considering these elements as the fundamental and essential attributes for the identity rendering of a digital architecture.

Notes

1. The CHROME project - Cultural Heritage Resources Orienting Multimodal Experience # B52F15000450001 - is an Italian national PRIN, funded by the MIUR Ministry of Education, University and Research.

2. S.C.O.P.E.R.T.A. Siti Culturali e Offerta di Percorsi Emozionali con Reti di Tecnologie Avanzate B53D18000130007 is a project funded by the Campania Region under the PON FESR 2014-2020 with the aim of implementing technology transfer procedures between research centers and local companies.

3. Scientific collaboration agreement for carrying out study, research, survey activities, aimed at a timely knowledge of archaeological and architectural heritage, necessary for any restoration, located in the area of competence of the Diocese of Teggiano-Policastro.

4. Tests were also carried out with threshold values of 5M and 3M with unsatisfactory final results in terms of IT management.

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Digital & Documentation is a Study day, a moment of scientific-cultural exchange and updating that has reached its third online edition with the online meeting organized in Rome. The main purpose of the initiative is to ensure an update of scientific innovations in the field of digital documentation of Cultural Heritage, aimed at its reading, preservation and enhancement.

The documentation of Cultural Heritage has assumed, today more than ever, a fundamental role in the collective global cultural horizon: more and more frequently we are witnessing the occurrence of natural and sometimes even man-made events, which undermine the preservation of cultural assets. Therefore, it is essential to update the documentation of Cultural Heritage, intended in its broadest meaning, which brings together tangible and intangible assets belonging to man-made and natural space.

The D&D meeting becomes the scene of debates, comparison and demonstration of innovations, refinements, testing, methodologies, experimentations relating to acquisition process, critical and semantic analysis, dissemination and divulgation of Cultural Heritage.