Lecture Notes in Mechanical Engineering

Cristina Manchado del Val
Miguel Suffo Pino
Ramón Miralbes Buil
Daniel Moreno Sánchez
Daniel Moreno Nieto *Editors*

Advances in Design Engineering IV

Proceedings of the XXXII INGEGRAF International Conference 21–23 June, Cádiz, Spain

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ISSN 2195-4356 ISSN 2195-4364 (electronic)
Lecture Notes in Mechanical Engineering
ISBN 978-3-031-51622-1 ISBN 978-3-031-51623-8 (eBook)
https://doi.org/10.1007/978-3-031-51623-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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Preface and Acknowledgements

INGEGRAF 2023 Conference originates as the 32nd International Conference on Graphics Engineering INGEGRAF 2023, held on June 21–23, in Cádiz, Spain.

INGEGRAF 2023 has been organized by the Graphic Expression Area of the Department of Mechanical Engineer and Industrial Design of the University of Cádiz.

Cutting-edge topics in Product Design and Manufacturing, Innovative Design and Computer Aided Design were especially encouraged. The list of topics (and subtopics) covered in the present edition are the following:

- Applied Graphic Engineering: Photogrammetry, reverse engineering, virtual reconstruction, Augmented, virtual and mixed reality, Image processing and analysis, Innovations in BIM/CAD/CAM/CAE, Biomodelling, digital sculpture, rendering and animation, Simulation and computer graphics, Building, urban planning and historical heritage, Shipbuilding, aerospace and industrial construction, Cartography, GIS and other geotechnologies.
- Product design and development: Innovation in design and creation of new products, Green engineering, User experience centred design, Modelling, parametric design and simulation-based design, Ergonomics and human factors, Emotional engineering, perception and product evaluation.
- Manufacturing and industrial process design: Additive manufacturing, Subtractive and Conformational Manufacturing, Industry 4.0 and digital twin, Design based on integrated product management, Product life cycle analysis (LCA), Manufacturing systems for new products, Characterization, verification and measurement systems.
- Education and Representation Techniques: Theoretical and applied geometry, Tools for graphic design, Innovative teaching, New approaches to teaching/learning, Graphic applications in engineering, Representation techniques and industrial drawing.

Some cross-cutting themes applied to the previous themes such as Sustainability, Innovation and Creativity Methods, Collaborative Engineering, Industrial and Intellectual Property Management, Research Methods and Design are also included.

We would like to thank our main organizer/institutions and the rest of the sponsoring/collaborating companies and institutions for their support and grants.

We would also like to express our gratitude to the members of the different committees for their support, collaboration and good work. Thanks to all reviewers for their selfless effort in reviewing contributions, which positively influenced the quality of the final papers presented at the Conference.

Last, but not least, thanks to all the participants of INGEGRAF 2023.

Cádiz, Spain
September 2023

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Applications of Photogrammetry for the Reproduction and Substitution of Ornamental Elements on the Façade

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1 Introduction

1.1 Conservation of Architecture Elements

Architecture must be understood as a discipline capable of articulating and engaging the necessary processes to respond to one of the great concerns of our civilization: living [1, 2]. In this context, the human being has not ceased in his work of adapting and modifying the space, the place. Conservation of architecture in certain parts of cities, particularly the ancient part, involves the protection and preservation of buildings, monuments, and other cultural heritage sites that have historical, cultural, and social significance. Through architecture conservation, we can protect the unique cultural identity and historical significance of our communities and cities. In these areas, buildings may have been constructed using traditional techniques and materials, and may be of great value to the community in terms of their cultural heritage and historical significance. The conservation of architecture in these areas often involves a balance between preserving the original character and features of the buildings, while also ensuring that they are safe and functional for current and future generations [3]. Conservation efforts may include measures to protect the building from damage, such as through regular maintenance and repair work, as well as restoration work to repair any existing damage. Likewise, at present, the conservation, analysis and enhancement of heritage (especially in its most tangible expression, such as architecture) continues to be a source of research and development [4, 5]. Preserving what exists is a social, cultural and anthropological concern, as is reconstructing the cultural historical legacy or consolidating its status [6]. That is why part of the research try to know, investigate, describe or even reproduce the shape or nature of the elements that are part of and make up the heritage section [7]. These

C. Manchado del Val et al. (Eds.): INGEGRAF 2023, LNME, pp. 1–10, 2024.
https://doi.org/10.1007/978-3-031-51623-8_1

elements start from the architectural or material ensemble that belongs to a specific civilization or society, and are key and indissoluble pieces of our essence, history and culture as individuals.

1.2 Contribution of Technology to the Conservation of Building Ornamental Elements

Architecture conservation is essential for preserving our cultural heritage, including historic buildings, landmarks, and other structures. Cultural heritage has recently advanced and broadened the categories and natures of resources to be preserved [8]. Sustainable architecture conservation practices can help ensure that our cultural heritage is preserved for future generations to enjoy, while also minimizing the impact of human activities on the natural environment. In this sense, technology has advanced significantly in recent years, making it easier to build 3D models of buildings for conservation and preservation purposes.

Digital imaging and modeling technologies are valuable tools in the conservation process. Laser scanning and photogrammetry can be used to create highly detailed 3D models of buildings and their elements [9], allowing conservation professionals to analyze and document the structure in detail. These models can also be used to plan and simulate restoration work, ensuring that conservation efforts are accurate and effective. Technology, in this sense based in non-invasive techniques, is a booming sector that is revolutionizing the world of photogrammetry and 3D scanning [10]. Digital photogrammetry has become an indispensable tool for the 3D digital reproduction of real elements, regardless of the purpose for which the process is carried out (Fig. 1). Digital photogrammetry not only stands out for the precision achieved thanks to technical means, but also for being an accessible and viable technique in many different application scenarios. Virtual 3D models and digital reproduction, together with virtual and augmented reality, have made it possible to solve the lack of access in certain architectural elements, or to generate digital models that allow a deeper analysis of the whole [11].

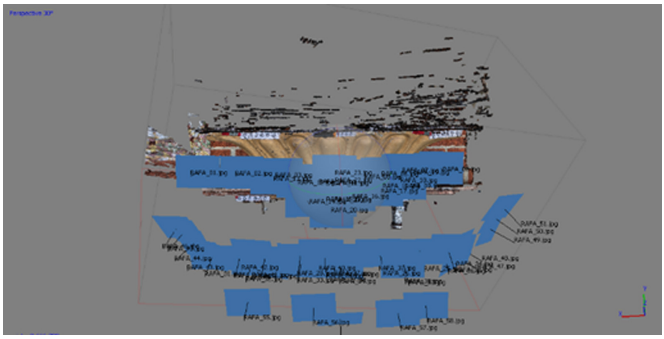


Fig. 1. Screenshot of the program creating the model of part N2.

This study aims to establish and systematize the reproduction process of ornamental elements in the façade of historic buildings by photogrammetry, using versatile and

lightweight materials. This research presents the results and achievements obtained in the Granada rehabilitation project, in contrast to the current situation and means of digital photogrammetry and other technologies used for similar purposes, proposing alternatives and other possible technical adaptations.

2 Methodology

According to Molero Alonso [12], the development of the recovery and conservation process of ornamental elements follows the following phases in an orderly manner:

A) Research and study of the starting point.
   1) Study of the regulations in force that may affect the property.
   2) Field inspection.
   3) Data collection and processing.

B) Development and manufacture of the digital model.
   4) Construction of digital models from photographs.
   5) Checks and validation of the dimensions in the generated model – precision of details.
   6) Reproduction by numerical control of the pieces on expanded polystyrene covered with mortar.

C) Element installation.
   7) Putting the pieces in place.
   8) Checking the status of the pieces.

Geometric documentation refers to the process of creating accurate and detailed measurements of architectural elements using specialized tools and techniques such as laser scanning, photogrammetry, and 3D modeling software [13]. The aim of this process is to create a digital replica of the original structure that can be used for various purposes, including preservation, restoration, and dissemination of cultural heritage. This study focuses on the use of subtractive manufacturing processes to create ornamental elements on the façade, and its end-use applications, by using the Computerized Numerical Control (CNC) techniques. These techniques consist of the use of subtractive technologies [14]. Subtractive manufacturing offers various materials and finishing processes. Softer materials are easier to machine into the desired shape but wear out faster. The manufacturing approach involves the use of EPS expanded polystyrene as a base material, which is then covered with a layer of acrylic mortar. The combination of these materials offers significant advantages that are difficult to achieve with traditional molding techniques. In addition, the acrylic mortar coating improves the weather resistance of the pieces, making them suitable for applications on building facades.

Digital dissemination of heritage architectural elements involves using technology to make information about these elements widely available to the public in general. By using digital tools to share information about heritage architectural elements, researchers, historians, and members of the public can learn about these structures regardless of their location or access to physical resources.

This work has been highly conditioned by the location of the “in situ” pieces, placed on the façade without the possibility of transferring them to the laboratory. Therefore,

the use of more sensitive equipment that can be used in the laboratory, such as the structured light scanner, is ruled out. Likewise, and due to the existence of scaffolding that covered the façade, other digitization technologies have been ruled out, such as aerial photogrammetry with drones.

2.1 Advantages of the Use of CNC Techniques

Some of the advantages of these techniques are:

- Personalization and uniqueness: subtractive manufacturing allows the creation of highly personalized ornamental elements. Each piece can be individually designed and manufactured to the specific requirements of the façade. This allows unique designs that enhance the aesthetic appeal and exclusivity of the architectural project.
- Precision and accuracy: subtractive manufacturing processes, with computer numerical control (CNC) technology, offer high precision and accuracy in the creation of ornamental elements. This ensures consistency in shape, dimensions and intricate details, resulting in a cohesive and visually pleasing façade design.
- Efficient production time: this CNC technology is suitable for the small-scale production of ornamental elements. Therefore, in the case of manufacture several pieces simultaneously, the needed production time is reduced and allows faster completion of the project under study.
- Cost effective for small quantities: subtractive manufacturing allows the production of smaller quantities without the need for expensive molds, thus accommodating limited constraints.

3 Results

It should be noted that the limitations associated with photogrammetric work have been favorably resolved without affecting the precision and quality of the results. The encountered limitations found in the inspection phase were:

- Lighting conditions: the lighting of the façade varies throughout the day, causing changes in shadows and reflections. In our case, the data collection was carried out when the façade was not affected by sunlight, thus avoiding bad lighting, not affecting the quality of the images.
- Accessibility: it is important to highlight the difficulty for data collection of some pieces located in areas of difficult access or at height. Sometimes it has been quite a challenge to capture high-resolution images from all the necessary angles. The limitation caused by accessibility resulted in incomplete data or low-quality images that affected the accuracy of the reconstructed model. However, it was solved by carrying out a higher number of shots using auxiliary structures.
- Image quality: the quality of the images plays a crucial role in photogrammetry. A Canon EOS 500D reflex camera with 15.1 MByte resolution was used for the work.
- Lack of control points: in our case, the points have been clearly identified, thus being able to correctly establish the scale, alignment and georeferencing of all the pieces addressed.

- Complexity of the surface: The inspection analyzed the complexity of the ornamental parts of the façade, as well as intricate textures, ornamentation or irregular shapes, etc. This limitation was solved by increasing the number of shots for those areas, causing greater overlaps to generate a complete and accurate 3D model.

To mitigate these limitations, a step prior to field work defined as "prior inspection on site" has been implemented. This inspection consists of carefully planning the data acquisition process, the equipment to be used, the estimation of the number of captures to be made, as well as the points of view, optimizing the lighting conditions to apply solid photogrammetric techniques.

Having implemented photogrammetry as the technology to create highly detailed and accurate 3D models of the different ornamental elements, some descriptions are identified. Table 1 indicates the number of photographs necessary for the creation of digital models of each piece identified with its code after carrying out the previous methodology.

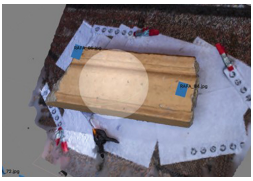
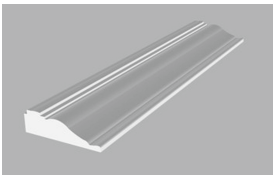
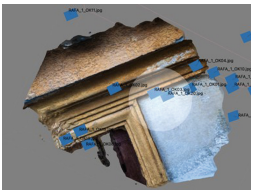
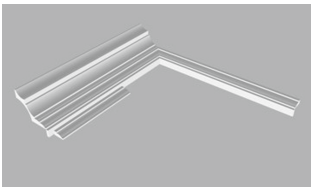
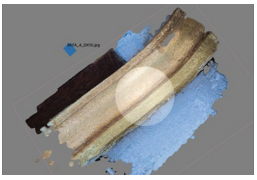
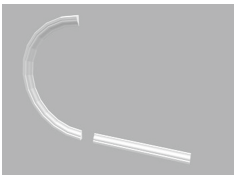
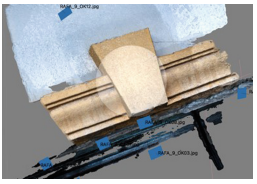
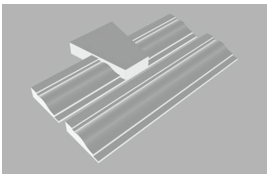
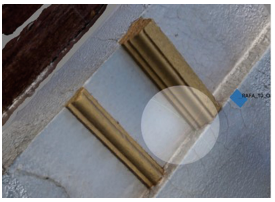
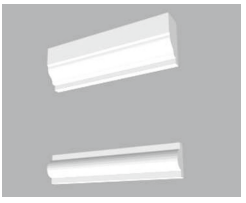
Likewise, Fig. 2 shows the sequence of photographs taken to digitize one of the eleven pieces of the Project (N1).

Table 1. Description of the element and number of photos.

Code	Part description	Number of photographs	Location
M1	Ornamental plaster cornice, placed horizontally on the façade and window lintels	34	Cabinet
M2	Window corner trim (jamb and lintel), combined with upper cornice, both in plaster	41	Façade
M3	Round arch and plaster false pillar	16	Façade
M4	Lintel with key and lintel without key in plaster for passage between rooms	18	Façade
M5	Double decorative molding in plaster installed on a wall in a horizontal position	26	Façade
M6	Plaster molding around window opening	18	Façade
V1	Plaster finishing at the base of the false abutment (type 1)	18	Façade
V2	Plaster finishing at the base of the false abutment (type 2)	12	Façade
V3	Plaster keystone on semicircular arch	25	Façade
N1	False plaster balcony support with flower motifs	100	Façade

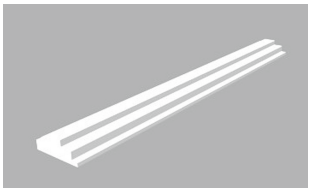
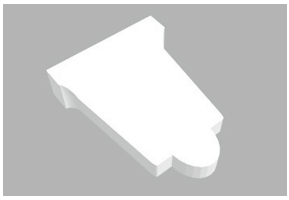
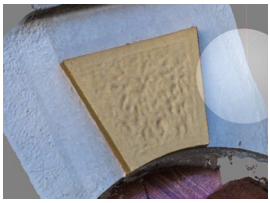
Table 2 shows the reproduction made of each piece via the use of photogrammetry. Firstly, the parts were created and secondly, they were identified in order to create the digital models that gave rise to the replicas.

Table 2. 3D models of the parts

Initial model	Revised model	Code	Number of photos valid/invalid	Number of points
		M1	33/0	5482
		M2	40/1	7007
		M3	16/0	4557
		M4	17/1	5204
		M5	26/0	4129

(*continued*)

Table 2. (*continued*)

Initial model	Revised model	Code	Number of photos valid/invalid	Number of points
		M6	18/0	5226
		V1	18/0	4183
		V2	12/0	2812
		V3	25/0	6024

(*continued*)

The resulting models are ready to be printed, presenting the following final appearance prior to reproduction (Fig. 2). The ornamental elements made are put in place using an adhesive that guarantees the stability and fixation of the piece regardless of temperature changes and wind action (Fig. 3).

4 Conclusions

From a technical perspective, the project has been identified as novel. After consulting regulations, the suitability and potential of both the technique (terrestrial photogrammetry) and the material used (EPS coated with acrylic mortar) were evaluated, endowing the aforementioned project with an innovative character in the field of ornamental element

Table 2. (*continued*)

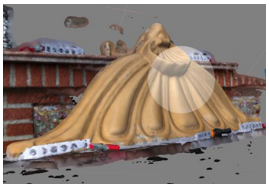
Initial model	Revised model	Code	Number of photos valid/invalid	Number of points
		N1	100/0	8325
		N2	59/2	7367

Fig. 2. Revised digital model (M1).

replacement. The novelty of this project could be checked versus other projects where the precast elements were made of traditional concrete. The experience of the technical team concluded that the pieces made with expanded polystyrene EPS covered with acrylic mortar are much more economical, durable and manageable in the installation processes on facades.

This work studies the transversality between graphic engineering and architecture and how they have coexisted during the project whose link has been photogrammetry. In this context, photogrammetry sits at the intersection of graphic engineering and architecture, providing common tools and methodologies for the documentation, design,