Il contributo della Geomatica al progetto di Restauro: evoluzione di tecnologie e pratiche di rilievo in quindici anni di esperienze didattiche condivise

The contribution of Geomatics to the Restoration project: evolution of survey technologies and practices in fifteen years of shared teaching experiences

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Negli ultimi due decenni, l'insegnamento del rilievo architettonico è cambiato grazie ai progressi tecnologici e metodologici. L'uso di scanner laser, droni e software di fotogrammetria ha rivoluzionato l'acquisizione dei dati, rendendo il rilievo più preciso e rapido. La digitalizzazione ha facilitato la creazione di modelli 3D, migliorando l'analisi e la documentazione degli edifici per progetti di conservazione e restauro. Il curriculum del rilevatore ora include competenze interdisciplinari da informatica, computer vision, cartografia storica e moderna, diagnostica e ingegneria strutturale, producendo rilievi più completi e dettagliati. Inoltre, i costi ridotti della tecnologia e del software hanno reso gli strumenti avanzati più accessibili a professionisti e studenti.

In the last two decades, the teaching of architectural surveying has changed thanks to technological and methodological advances. Using laser scanners, drones and photogrammetry software has revolutionized data acquisition, making surveying quicker and more precise. Digitization has facilitated the creation of 3D models, improving the analysis and documentation of buildings for conservation and restoration projects. The surveyor's curriculum now includes interdisciplinary skills from computer science, computer vision, historical and modern cartography, diagnostics and structural engineering, producing complete and detailed surveys. Additionally, the reduced costs of technology and software have made advanced tools more accessible to professionals and students.

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Premise

Coming from a faculty of Civil Engineering, as a research fellow, I had taught courses in Topography, Photogrammetry and Numerical Cartography; when I arrived at the Architecture courses in 2007, I initially needed direction. I immediately realised that the architectural surveys I had experience with, all carried out after the mid-90s as a student of the courses of prof. Ambrogio Maria Manzino, were very different from the exercises that I could have proposed to my new Architecture students. For the photogrammetric shots, we used the Rolley 6006 semimetric with 60×60 mm film, and we rendered the surveys in stereoscopy by mounting the frames on the Stereobit 20 of Galileo Siscam. The architectural object was rendered for 3D polylines in CAD, which provided a 'wireframe' representation. In my drawing courses, I continued to use the drawing board, pencils and Indian ink Rapidographs. Also with a view to managing photogrammetric surveys, I taught myself to use the AutoCAD software and its automation functions in AutoLISP language.
It has only been about ten years since my experience as a student and my first experience as a teacher at the Faculty of Architecture but these have been years of incredible transformations in Geomatics techniques and tools. I started with my degree thesis by dealing with laser scans from an aerial platform and developing numerous Fortran language algorithms to process this data. Later, duringmy PhD in Geodesy and Geomatics obtained at the Polytechnic of Milan, I dealt with entirely different topics, from networks of permanent GNSS stations for positioning services and monitoring deformations in aerial photogrammetry, from geodetic reference systems to the analysis of time series of geodetic coordinates. I learned to use the Geosoft GCarto digital photogrammetric rendering workstation in aerial photogrammetry work. However, the photogrammetric rendering was still manual, and there was no talk of photogrammetric point clouds or structure from motion algorithms.
My new students had to survey the architecture and draw it. At this point, I thought I knew a lot because, as a student, I was always a decent draftsman. Yet even in this field, I immediately realised that I spoke a different language to an engineer and I had difficulties communicating the simplest things. My first experience was in the "Architectural survey laboratory", which included credits in Drawing and Surveying. I am still determining what I could teach in that course, but I began learning from colleagues and the students themselves. This was followed by other laboratories, which took the name of "Geomatics Laboratory for Architectural Modelling", and the first collaborations with the Restoration Ateliers. Working with them and with the students, especially during the classroom reviews of the survey drawings, I began using a different language to develop my experience in the survey of architecture and to understand what needs an architectural survey should meet.
The experience that was undoubtedly the most formative for me from the point of view of the survey for the restoration project was the meeting with Professor Carla Bartolozzi. Our collaboration in the Restoration Ateliers began in 2010, with the Molino Ugliengo restoration project in Santhià, and continued until this year. Fifteen years of uninterrupted partnership were, first and foremost, a school for me.
From the first to the last day of working with Carla Bartolozzi, I benefitted from her vast expertise and extensive knowledge in architecture and restoration. During the organisation of the Ateliers, I learned from

her the technical and specialised language of these disciplines and the methodological and critical approach needed to tackle restoration projects rigorously and creatively.
One of the most enriching aspects of our collaboration was the joint work during the revision of the works produced by the students. In these sessions, we discussed the errors and solutions, analysed the problems and design ideas, and assessed the opportunities offered by the different approaches. This revision process allowed the students to improve their projects and stimulated a continuous and constructive dialogue between us and them.
The students appreciated our ability to interact with them openly and collaboratively, creating a dynamic and stimulating learning environment. The continuous interaction between the disciplines of surveying and restoration has allowed us to adopt an interdisciplinary approach that has significantly enriched the students' educational experience, promoting a more complete and integrated understanding of restoration projects, allowing them to see how different skills and knowledge can be combined to address the complex challenges of architectural restoration. Working with Carla Bartolozzi has been an experience of continuous enrichment for me and a stimulus to approach teaching activities with competence and creativity.
This paper does not aim to offer a comprehensive overview of the development of three-dimensional survey techniques. Instead, it outlines how these techniques have evolved over 15 years through the perspective of students and their survey drawings and how they are taught as part of preliminary architectural surveys for restoration projects.

Introduction

The teaching of architectural surveys has undergone significant changes over the last 20 years, mainly thanks to technological advances and the integration of new methodologies. Introducing 3D laser scanners, drones and new photogrammetry software has revolutionized architectural surveys. These tools allow the acquisition of data with precision and speed, something which was unthinkable until a few decades ago. By contrast, digitization has allowed the creation of detailed and high-quality 3D models, facilitating the analysis and documentation of buildings and enabling better documentation for the conservation and restoration of architectural heritage.
The teaching of architectural survey now integrates skills from different disciplines, such as computer science and computer vision, historical cartography and modern digital cartography, diagnostics and structural engineering. This interdisciplinary approach has enriched the field and has allowed survey projects to be approached from a broader perspective. Universities and training institutes have increased the emphasis on practical training, allowing students to directly use new technologies and acquire valuable skills that will be fundamental in their professional future. Also, with the lowering of the costs of technologies and software, architectural surveying has become more accessible, allowing more professionals and students to use advanced tools in their projects.
Students always begin their survey work by evaluating and verifying any existing survey documents. By checking and completing them, they can critically assess the material provided, its metric reliability and its information content.

1. Photographic documentation

In the Restoration Workshops, we have always given space to the quality of photographic documentation. Photography can have a significant metric and historical value in architectural documentation. We will talk about the metric use of photography later. Still, we must note that photography has a significant historical value, especially when accompanied by a date and contextual references. This value is manifested by providing a visual testimony of how buildings and sites were in the past, showing their evolution and highlighting alterations, extensions and restorations. It can also monitor changes over time, such as lesions or structural deformations, providing a visual record that can be measured and analyzed. Photographs document architecture and the cultural and social context in which a building existed or was used. They can ultimately guide restorers in their choices during the restoration project, providing details on materials, colours and decorations.
It is often challenging for students to take care of the quality of photographic documentation. Even though they are used to taking pictures with their smartphones, they need to become more familiar with reflex or mirrorless[1] cameras. We provide them with essential knowledge, guiding them in their use, which is necessary for a quality photogrammetric survey. Of course, the smartphone can be used for metric purposes too, but the quality we can obtain using professional optics and sensors is hard to achieve using a smartphone, especially in difficult lighting conditions.

2. From perspective straightening to automated 3D modeling

One of the first photographic survey techniques taught in Architecture degree courses is the perspective straightening of a photograph. This technique, essentially a homographic transformation of a picture, allows the elimination of perspective deformation for flat or plane-like objects, such as a document, a painting or even the façade of a building without excessive projections and recesses. The homographic transformation is a roto-translation with anisotropic scale variation, angular sliding and angular convergence; it is described algebraically by eight parameters that can be estimated if the topographic coordinates of at least four support points are known. It is appropriate and advisable to eliminate the radial distortion introduced by the objective lens before applying the homographic transformation. These operations are now facilitated by easy-to-use software, available also as freeware.
In architectural surveying, however, we often find buildings with more complex elevations that also move away from the condition of a flat object, with significant projections such as frames and balconies or recesses such as niches and porticoes. To minimize the residual perspective deformation and get closer to the conditions of parallel projection, the photograph can be taken with a long focal length lens and narrow field angle, moving the point of view away and raising it to a height equal to half the height of the elevation. It is also possible to treat each depth of the elevation as a separate plane.
The elevation survey is obtained by interpreting the straightened photograph, which is still geometrically a central projection, drawing in parallel projection. Students encounter the most significant difficulties in this phase because they tend to draw in central projection, seeing projections and recesses still in perspective.

1 Thanks to a series of technological developments that make them more versatile and advanced, mirrorless cameras are currently replacing the SLR system. Big brands such as Canon, Nikon and Sony are focusing on developing mirrorless technology, gradually reducing the production of new SLRs. Professional photographers are also switching to mirrorless cameras, attracted by their advanced features and greater portability.

Thanks to the progress of digital photogrammetry and computer vision, since the early 2000s, the use of Structure from Motion (SfM) algorithms has spread in architectural surveying and photogrammetry, which, despite being considered by some as having been definitively technologically surpassed by laser scanning, has experienced a new life and increasingly advanced automation of the three-dimensional modelling process. SfM algorithms have been used more and more frequently in various architectural survey projects due to their efficiency and relatively low cost compared to traditional methods. Universities and research institutes worldwide have contributed to their diffusion, developing increasingly sophisticated software and algorithms. This technique has become particularly popular for its ability to create detailed and accurate 3D models starting from simple photographs, making it a valuable tool for documenting and conserving architectural heritage.
In the first significant teaching experiences of Architecture with the new digital photogrammetry techniques proposed in some degree theses, students initially used Photomodeler[2], Bundler[3] and VisualSFM[4] software. This software paved the way for the advent of Agisoft Phoscan, the first version of which was released in 2010 by Agisoft LLC. Photoscan combined high performance with unprecedented ease of use and brought digital photogrammetry to a new level of accessibility and precision in the years that followed. This software, later renamed Agisoft Metashape and acquired by the Trimble group, became very popular for several reasons, offering an intuitive interface that allows even less experienced users to create detailed 3D models from photographs, making photogrammetry accessible to a broader audience. The software is known for its ability to generate highly accurate and detailed 3D models used in various fields such as architecture, archaeology, geology and cultural heritage conservation. It includes many automated features that simplify the 3D modelling process, reducing the time and effort required to achieve high-quality results. Agisoft has built a strong user community and offers good technical support, including tutorials, forums and detailed documentation, which help users troubleshoot and improve their skills. Metashape is relatively affordable, offering good value for money compared to other professional photogrammetry solutions. Students can try out all the software's features and save their models using a 30-day trial license. Thanks to the availability of efficient and easy-to-use photogrammetry software, I have also abandoned the teaching of perspective rectification in the three-year degree courses, encouraging photogrammetry even for the most straightforward cases. Although many students have yet to gain experience in 3D modelling or three-dimensional drawing on CAD, photogrammetry provides a two-dimensional product, the orthophoto, which, like photographic rectification, can be used to draw a view in parallel projection. The orthophoto is a parallel projection of the three-dimensional model on a projection plane fixed at will or using topographic support points. It has photographic quality and can be used to develop architectural design or analyse degradation.
Starting from the first Atelier held at Castello di Masino (TO) in the spring of 2014, we introduced the use of the drone for the photogrammetric survey of the context and the roofs of the building. This tool has proven particularly useful for providing an initial general survey for the large-scale framing of the project theme and the master plan presentation phase.
The aerial photogrammetric survey by drone has always been carried out in all subsequent ateliers. In the case of Frinco Castle (AT), an

2 One of the first photogrammetry software used to create 3D models from photographs. It has been widely used in various fields, including engineering and architecture.
3 Developed by Noah Snavely and colleagues, this software played a crucial role in developing SfM techniques. Bundler was used to reconstruct unsorted photos and laid the foundation for many modern methods.
4 VisualSFM has contributed to popularising SfM techniques and is known for its ability to handle large data sets and its integration with other photogrammetry tools.

aerial LIDAR scan was also conducted using a DJI Matrice 300 RTK drone and L1 sensor. We generally provide students with both the aerial frames and the already developed aerial photogrammetric model and aerial orthophoto, because the aerial survey always requires the processing of a very high number of frames, which can be too computationally expensive for the hardware at their disposal.

3. Metric surveying: from direct survey techniques to SLAM

In my early teaching years, I always dedicated some classroom hours to teaching direct survey techniques. Despite the extraordinary evolution of survey techniques that has occurred in recent years, I have always supported the teaching of this discipline and I believe that knowledge of its fundamental principles and a minimum amount of practice are necessary. Often, for practical and economic reasons, and also ease of execution, the professional architect may need to survey using only photogrammetry, without topographic support. Photogrammetric rendering is still possible but, in this case, the direct survey provides the survey with the correct scale factor and a minimum of dimensional control. Mastery of this practice can enable students to independently conduct a simple survey with acceptable dimensional tolerances for the study purposes they set themselves and with a very satisfactory quality of the graphic works.
In the Restoration Workshops, however, we have traditionally provided students with topographic support for the survey, creating a topographic framing network and measuring photogrammetric support points on the building elevations with a prism-free total station. Topographic framing is essential not only to provide orientation and a dimensional reference but also to include each survey in a standard reference system, integrating the surveys carried out by the various work groups into a single overall survey, valid for the restoration project at masterplan level.

4. The experience of distance learning during the lockdown

During the lockdown caused by the COVID-19 pandemic, the teaching experience underwent a radical transformation, moving from traditional in-person teaching to remote learning. University closures were sudden, forcing teachers and students to adapt to online teaching quickly and requiring great effort to prepare digital tools and new teaching methodologies.
Teaching in all surveying disciplines encountered challenges in overcoming obstacles because of the impossibility of the students to conduct surveys in person. Teachers had to experiment with new teaching methodologies and digital tools, somehow enriching the learning experience, impoverished of field experience.
We chose to work on a theme, a portion of the Borgo Castello at La Mandria di Venaria Reale, where I carried out the metric surveys with the acquisition of three-dimensional scans, photographs of the elevations and complete photographic documentation. This data was given to the students, allowing them to produce the survey documents and tackle the subsequent phases of the work, from the degradation analysis to the restoration project.

The students could participate in a virtual topographic measurement session during the online lectures. By using the integrated Trimble SX10 total station, sharing the controller screen in the Virtual Classroom and framing the operations in the field with a webcam, it was possible to show the students all the phases of the survey, the setting up of the instrument, the collimation of points with and without a prism, the acquisition of three-dimensional scans and spherical panoramas.

5. Evolution of the graphic survey documents

Whether the three-dimensional survey technique is photogrammetry or laser scanning, the raw three-dimensional product is a point cloud. Starting from this, in recent years, some more passionate or enterprising students have developed three-dimensional models of notable quality, creating perspective views, axonometric sections and even virtual tours of the building. However, the need to produce architectural drawings, plans, elevations and sections and to correctly approach the design of the construction elements starting from the point cloud remains predominant. Numerous software tools can be used in this phase but, to avoid confusing the ideas of the student tackling a three-dimensional survey for the first time, it is advisable to limit the choice to the bare minimum. Integrating photogrammetric and laser scanning point clouds in the same Metashape software is possible using only this tool to extract the documents. There are, however, more efficient choices. The extraction of section profiles can be done directly in AutoCAD. However, many students appreciate CloudCompare software, which allows all the fundamental editing operations on the point clouds. CloudCompare has the advantage of being open source and free software, and it can visualize and process both point clouds and 3D triangle meshes. Developed initially to compare dense point clouds quickly, CloudCompare is now used for a wide range of editing and three-dimensional analysis operations. It supports various file formats and offers advanced segmentation, registration, distance calculation and statistical analysis tools.

Regardless of the software, the section profile extracted is only the metrically reliable reference trace for drawing the architectural section. The section profile must be interpreted by studying the architectural elements present, brackets, frames and mouldings, the shape of the openings and the types of windows and roofs. At this stage, students are encouraged to refer to the manuals, where it is always possible to find similar building typologies.

Recently, some students have chosen to create the BIM (Building Information Modeling) model from a point cloud, detailing it with the addition of windows, finishes, furnishings and systems. The BIM model automatically extracts plans, sections, elevations and construction details. These drawings are accurate and up to date, reflecting all the changes made to the 3D model. The architectural drawings are verified and revised to ensure compliance with the regulations and project requirements. Any changes should be made directly to the BIM model to ensure consistency between the 3D model and the architectural drawings, which are then prepared for delivery with the inclusion of annotations, dimensions and legends. The credits available in the Restoration Ateliers do not allow this topic to be addressed. However, it is a starting point for further study that can be suggested to students.

Appendix: Key Themes of the Restoration Ateliers 2010-2024

The Restoration Atelier was named “Atelier Compatibilità e sostenibilità del restauro architettonico” until the 2020/21 academic year, and “Atelier di Restauro e conservazione integrata” starting from the 2021/22 academic year.

2010 Santhià (VC), Molino Ugliengo
2011 Santhià (VC), castel and village of Vettigné
2012 Ricetto of Pavone (TO)
2013 Castle of Orio Canavese (TO)
2014 Castle of Masino (TO)
2015 Castle of Masino (TO)
2016 Staffarda Abbey (TO)
2017 Farmhouses of the Staffarda Abbey (TO)
2018 Stupinigi, rural buildings (TO)
2019 Stupinigi, rural buildings (TO)
2020 Venaria Reale (TO) - Borgo Castello during lockdown
2021 Venaria Reale (TO) - Borgo Castello
2022 Frinco castle (AT)
2023 Venaria Reale (TO) - Borgo Castello
2024 Sant’Antonio of Ranverso, the abbey and rural buildings (TO)