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UAS for Landscape and Architectural Survey: An Innovative Interdisciplinary Approach of Learning by Doing in the Bachelor Programs at Politecnico di Torino

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Abstract:
The elective course *"UAS for Landscape and Architectural Surveying"* offered in the Bachelor programs at the Politecnico di Torino has become increasingly relevant across a wide range of disciplines. These include Architecture, Urban Planning, but also Civil, Building, and Environmental Engineering, as well as Computer, Aerospace, Cinema, and Digital Media Engineering, fields in which Unmanned Aircraft Systems (UAS) are proving valuable beyond traditional surveying applications. Launched in 2017 through a collaboration between two Department of the Politecnico di Torino, the course has witnessed growing student enrollment, reflecting a rising interest in leveraging UAS to simplify, automate, and accelerate various tasks. Rooted in a *learning-by-doing* pedagogy, the course is organized into four main components. It begins with theoretical lessons covering drone legislation and classification, digital photogrammetry fundamentals, computer vision, and the Structure from Motion (SfM) methodology. This is followed by hands-on training in safe flying environments, where students pilot drones and carry out an actual survey of a designated site. In the next phase, students process datasets, particularly the ones they captured, using commercial SfM software. The final segment includes seminars showcasing drone applications in areas such as early warning, precision agriculture, and humanitarian missions. The course concludes with each group presenting their project, critically analysing results and tailoring discussions to their individual academic backgrounds, highlighting UAS versatility across disciplines.

1. Introduction

The innovative course *"UAS for Landscape and Architectural Survey"*, part of the elective offerings in the Bachelor programs at Politecnico di Torino, introduces students to tools, methods, and procedures for using UAS in photogrammetric surveys and applying the SfM approach.

Although not mandatory for any specific degree, it is open to students from Architecture, Urban Planning, and a wide array of Engineering disciplines, including Civil, Environmental, Computer, Aerospace, and Digital Media Engineering, where drone technology has broad potential (Shadiev & Yi, 2022). Traditional surveying methods (e.g., total stations, GNSS receivers, and terrestrial laser scanners) often demand significant fieldwork, technical expertise, and expensive equipment. UAS technology offers a faster, more flexible alternative, enabling efficient aerial data acquisition while shifting most processing tasks to the lab (Rinaudo et al., 2012). Based on computer vision and digital photogrammetry, the SfM technique allows students to generate dense point clouds, textured 3D models, digital terrain/surface models (DTM/DSM), and high-resolution orthophotos.

1.1 Teaching Activities

The course was introduced in the academic year 2017/2018 through cooperation between the Departments of Architecture and Design (DAD) and Environmental, Land, and Infrastructure Engineering (DIATI). Two research groups, the Laboratory of Geomatics for Cultural Heritage (Lab G4CH) and the GeomaticsLab, bring complementary expertise to the program, respectively focusing on built heritage and environmental applications like glacier monitoring or vineyard pest management.

As the first course of its kind in Europe, it has become a well-established component of the university's offerings. Over the last eight years, it has maintained an average enrolment of 70 students per year, peaking at 110 and rebounding to 41 after pandemic disruptions in 2022/2023.

Adopting a learning-by-doing approach, the course provides experiential learning opportunities in both data acquisition and processing, core to the geomatics profession. It fosters interdisciplinary collaboration, problem-solving, and communication (Balletti et al., 2023).

Students are expected to:

- Plan UAS-based photogrammetric surveys appropriate to the required level of detail.
- Process captured data to produce accurate, metric deliverables.
- Critically assess the quality, accuracy, and completeness of their results.

1.2 Course Organisation

The course consists of four integrated modules. The first covers theoretical concepts including photogrammetry, computer vision, image-based 3D reconstruction, drone components, and European UAS regulations. Students then learn how to design survey missions to meet target output specifications. In the practical phase, students work in teams (4-6 members) and practice flying drones in controlled environments. They learn to maintain correct image overlap and flight parameters.

This is followed by a half-day real-world survey using additional tools such as GNSS receivers and total stations for measuring the Ground Control Points (GCPs). Students are responsible for planning and executing a complete photogrammetric block. Next,

they process their data using commercial SfM software to generate dense point clouds, DSMs, and orthomosaics.

Finally, in the second part of the course a series of guest lectures explores UAS use cases beyond surveying, including disaster management and survey, agricultural monitoring, and international humanitarian efforts in collaboration with organizations such as UNICEF and the World Food Program.

2. Theoretical Lectures

The course opens with an introduction to Geomatics and its core technologies, including photogrammetry, laser scanning, geodesy, and remote sensing. Students are introduced to the historical development of Unmanned Aerial Systems (UAS), tracing their origins from early uses, such as the Austrian unmanned balloon attack on Venice in 1849, to the advanced multirotor and fixed-wing platforms in use today (Figure 1).

The fundamental components of modern drones are examined in detail, including the Inertial Measurement Unit (IMU), Global Navigation Satellite Systems (GNSS), onboard cameras, and various navigation and positioning sensors. A focus is also placed on typical payloads, such as RGB, thermal, and multispectral cameras, as well as LiDAR sensors, depending on the specific application. The potential applications of drone technology are presented across diverse domains, including infrastructure inspection, emergency response, precision agriculture, and cultural heritage preservation.

These examples provide students with an understanding of how UAS can address complex real-world challenges. Subsequent lectures explore the theoretical foundations of photogrammetry and Structure from Motion (SfM). Students are introduced to the geometric principles underlying image formation, such as central projection and the collinearity equations, as well as the concepts of interior and exterior orientation, and the steps involved in relative and absolute orientation.

These principles are later reinforced through hands-on activities using commercial SfM software (such as Agisoft Metashape Professional or Pix4DMatic). Emphasis is placed on the nature of digital imagery, including the radiometric content of pixels, the importance of lens calibration, and techniques for handling image distortions and planar transformations (Figure 2). Students learn to compute and apply Ground Sampling Distance (GSD) to flight planning, optimizing mission parameters to ensure effective coverage and data quality.

In the context of SfM, students are introduced to image matching techniques, including key descriptors such as Scale Invariant Feature Transform (SIFT) and Speeded-Up Robust Features (SURF), as well as matching strategies like cross-correlation, least squares matching, and both area-based and feature-based matching. The course also introduces feature extractors, blob detectors, and image filtering operators, which form the computational basis of modern 3D reconstruction workflows (Figure 3).

Finally, the course covers the Bundle Block Adjustment (BBA) problem, highlighting its central role in refining camera positions. Students are taught to assess the quality of their results through an understanding of errors, accuracy, and precision, and are introduced to optimization techniques such as the least mean square method. To address outliers and improve robustness, methods such as Random Sample Consensus (RANSAC) are also discussed.

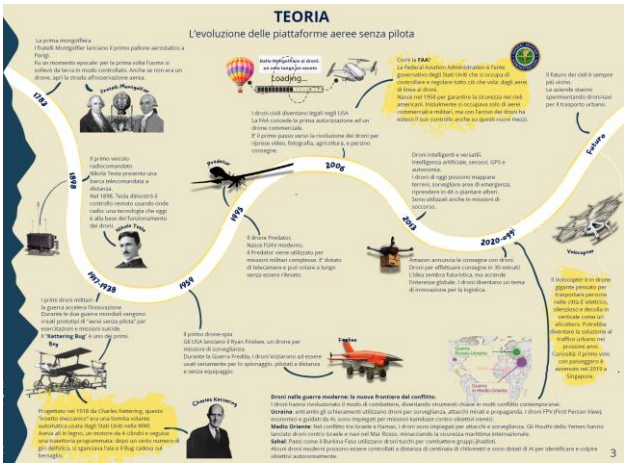

Figure 1. Example of Theoretical Final Products: The evolution of UAS through history, from hot air balloons to modern days.

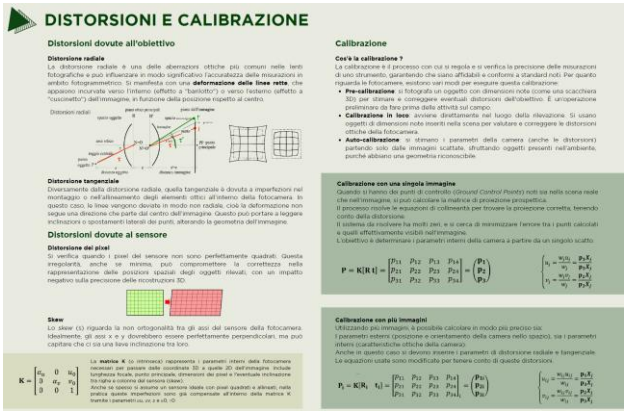

Figure 2. Example of Theoretical Final Products: The role of Lens Calibration and the different Distorsions.

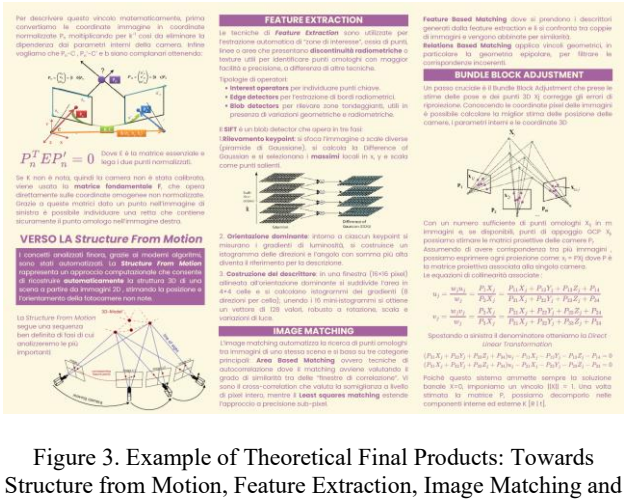

Figure 3. Example of Theoretical Final Products: Towards Structure from Motion, Feature Extraction, Image Matching and Bundle Block Adjustment

3. Practical Lectures

Building on the theoretical knowledge acquired in earlier lectures, students engage in practical activities designed to deepen their understanding of photogrammetric data acquisition using UAS. These sessions emphasize flight planning and hands-on flying operations conducted in controlled environments.

3.1 Flight Planning

Before any survey mission, a UAS operator must define several parameters that influence flight performance and data quality.

These depend on the drone's technical specifications, the nature of the case study, and the desired level of detail. Working with a simple spreadsheet, students are provided with relevant inputs and are tasked with determining key flight parameters, such as flight altitude, Ground Sampling Distance (GSD), image footprint size, flight speed, and shutter speed to avoid image blur. They also calculate theoretical flight time, an essential factor considering drone battery capacity and endurance.

Next, students compare their manually derived parameters with those generated by planning software like ArduPilot Mission Planner (Figure 4). They are also introduced to other platforms tailored to different UAS types, including eMotion for fixed-wing drones and mobile apps like Pix4DMapper and DJI Flight.



Figure 4. Flight Simulation over Villa della Regina via ArduPilot Mission Planner (2023/2024 case study)

3.2 Flying Operations

Once students understand the theoretical and planning aspects of drone operations, they begin pilot training in small groups using nano-UAS (under 250g) in a safe, enclosed facility at Politecnico di Torino (Figure 5).

Subsequently, they participate in a simulation exercise at a larger test site on the outskirts of Torino, in which they are also shown different kind of UAS they have learned about in the theoretical lectures. Here, they place GCPs and use GNSS receivers in NRTK (Network Real time Kinematik) mode to georeference them (Figure 6).

Students then conduct actual drone flights, adhering to proper overlap and altitude settings to ensure accurate data acquisition for photogrammetric processing.



Figure 5. Pilot training in an enclosed facility at Politecnico di Torino.



Figure 6. Fixed wing UAS demonstration (eBee X) and preliminary flying activities performed by students in a field.

3.3 Survey Activities

The practical module culminates in a half-day field survey. Following the learning-by-doing approach, students receive a brief introduction to total station operation and the basics of network adjustment, and then independently apply their skills in mission planning and UAS data acquisition with minimal tutor supervision.

Over the years, this final survey has evolved into a high-value exercise involving the documentation of cultural heritage sites, including several UNESCO World Heritage Sites (WHS) previously undocumented with photogrammetry. These surveys offer opportunities for interdisciplinary collaboration and knowledge exchange.

Past case studies have included in chronological order:

- Borgo Castello in the Parco La Mandria, the second-largest enclosed park in Europe.
- Borgo Medievale, a reconstructed medieval village and open-air museum;
- The mountain villages of Prali and Elva, representative of Alpine rural heritage;
- Villa della Regina, a royal residence in Torino surrounded by vineyards;

The last year's case study was the Reggia di Venaria Reale, one of the most significant Baroque residences in Italy and a key element of the Royal Residences of the House of Savoy, a UNESCO World Heritage Site since 1997.

Located just outside Torino, the Reggia was designed in the 17th century by architect Amedeo di Castellamonte as a grand hunting lodge and pleasure residence for Duke Charles Emmanuel II of Savoy. Over time, it evolved into a monumental complex that symbolized the power and prestige of the Savoy dynasty. The site features monumental architecture and carefully restored interiors (Figure 7), including the Church of Sant'Uberto, dedicated to the patron saint of hunters, and the Great Gallery of Diana, one of the most iconic examples of Piedmontese Baroque with its dramatic vaulted ceilings, natural lighting, and ornate stucco decorations by Filippo Juvarra.

These architectural spaces provide an ideal context for studying the integration of aerial survey techniques with built heritage documentation. Surrounding the palace are the Gardens of the Reggia, which span over 60 hectares and have been meticulously restored to reflect their historical layout. They include formal parterres, landscaped terraces, and tree-lined avenues, interspersed with fountains, sculptures, and contemporary art installations (Figure 8). These gardens not only showcase a dialogue between history and modernity but also offer diverse topographical and visual elements that are particularly well-suited for UAS-based surveying and 3D modeling.

The Reggia di Venaria thus offers a rich and varied environment for applying photogrammetric and geomatics techniques, bridging cultural heritage conservation with advanced surveying methodologies. Its complexity allows students to deal with different scales, textures, and types of surfaces, simulating real-world challenges encountered in professional heritage documentation and environmental monitoring projects.



Figure 7. Interior view of the Great Gallery of Diana.



Figure 8. Aerial view of the Gardens, with contemporary art installations, parterres and tree-lined avenues.

3.3.1 Followed methodology for data acquisition

Students are divided into four teams; each composed of four working groups. Each group is responsible for acquiring aerial images and measuring target coordinates: natural points on the facades and artificial points on the ground.

In turns, groups:

- Select and identify façade natural points and measure it using a total station (Figures 9 and 10);
- Plan drone flights for their assigned building area, determining flight strips, image count, and object distance;
- Survey target coordinates of the natural or artificial target positioned on the ground using GNSS receivers (Figure 11).

For this occasion, each group processes two datasets:

- Their own close-range acquisition of a specific portion of the building, with a flying distance between 5 and 10 meters, and maximum admissible GSD of 10 mm;
- A general flight dataset acquired by the Nucleo Operativo SAPR Regione Piemonte (a specialized firefighter UAS team), using a professional drone with higher-altitude capability and a heavier payload, flying at a height of 65 meters with a maximum admissible GSD of 10 mm.



Figure 9. Surveying natural and artificial points on the façade using a total station

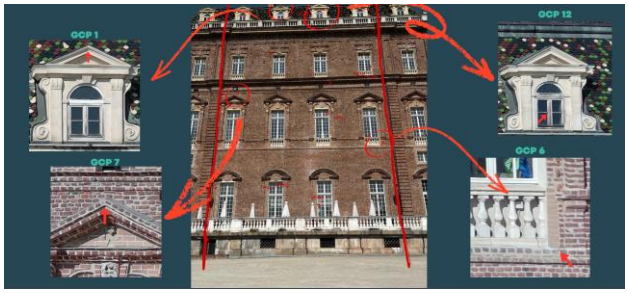

Figure 10. Example of the assigned portion of the façade with the annotation of the points to be measured.



Figure 11. Surveying natural and artificial points on the ground using GNSS receivers.

3.3.2 Instruments and Techniques

For the survey at Reggia di Venaria, the following instruments have been used:

- Total Stations: Leica FlexLine TS03, Leica Nova MS60 Multistation, Geomax Zoom 30 Pro;
- GNSS Receivers: Stonex S999, Stonex S990a, Leica GS18;
- Various Nano-UAS under 250 grams used by the students for acquiring the assigned portion of the façade (Table 1);
- A larger UAS operated by the firefighters' squad for acquiring the whole building roofing (Table 2).

Nano UAS	Main Specifications
DJI Mini 3 Pro	48 MP, 1/1.3" CMOS, f/1.7, 34 min of battery life
DJI Mini 3	48 MP, 1/1.3" CMOS, f/1.7, 38 min of battery life
DJI Mavic Mini	12 MP, 1/2.3" CMOS, f/2.8, 38 min of battery life
Autel EVO Nano II	50 MP, 1/1.28" CMOS, f/1.9, 28 min of battery life
DJI Spark	12 MP, 1/2.3" CMOS, f/2.6, 16 min of battery life

Table 1. List of Nano-UAS used by the students for the façade acquisition

Instrument	Main Specifications
DJI Matrice 350 RTK	55 mins of battery life, 2.7 kg of maximum payload, maximum takeoff weight of 9.2 kg, 810 × 670 × 430 mm
DJI Zenmuse P1	45 MP full-frame (35.9 × 24 mm), 4.4 µm pixel size, 3 axis-stabilization

Table 2. UAS used by the firefighters' squad for the general acquisition

4. Data Processing activities

Following the learning by doing philosophy that defines the course, the data processing phase guides students through the Structure from Motion (SfM) workflow using Agisoft Metashape Professional, a widely adopted commercial photogrammetry software.

After completing the theoretical lectures and practical fieldwork, students begin the data processing activities of the course with a simplified dataset acquired over a vineyard near Torino.

This initial case study enables them to understand the core steps of the SfM pipeline, including image alignment and relative orientation, camera calibration, and the identification and measurement of Ground Control Points (GCPs) with known coordinates. From this, students generate a series of metric and visual products such as a georeferenced dense point cloud, a textured photorealistic 3D model, a Digital Surface Model (DSM), and an orthomosaic. Once confident with the process, they repeat the same workflow on a more complex architectural dataset of Torre Chianca in Porto Cesareo (LE). In this second case, they also learn to produce vertical DSMs and orthomosaics of façades, expanding their capabilities beyond top-down surveys.

Finally, students apply their knowledge to process the datasets related to the Reggia di Venaria Reale, working both on the images they acquired themselves during the survey and on the larger-scale dataset collected by the firefighter UAS squad (Nucleo Operativo SAPR Regione Piemonte). This dual-dataset task allows them to compare flight planning strategies, camera settings, and outcomes across different types of UAS platforms and mission profiles.

Case Study	Required Level of Detail and Accuracy	UAS	N° of Images
Vineyard in Grugliasco	1:200 4 cm	DJI Phantom 4 Pro	40
Torre Chianca	1:100 2 cm	DJI Mavic 3M	100
Portion of Reggia di Venaria	1:50 1 cm	From Table 1	Varying
Roofing of Reggia di Venaria	1:100 2 cm	DJI Matrice 350 RTK	350

Table 5. List of processed case studies and main specifications

4.1 SfM commercial employed software

Following the theoretical explanation of photogrammetric principles, students are introduced to the practical workflow of a 3D reconstruction using the well-known Agisoft Metashape Professional (in the course the demo version of metashape 2.2.0 was employed).

The reconstruction process is structured into a series of methodical steps, each requiring the definition of key parameters to ensure the generation of accurate and high-resolution metric products.

- Image Alignment, the initial step in which the software detects and matches features across overlapping images using algorithms such as SIFT. The main parameters include the accuracy level (set to Medium or High base on the students' PC performance), the key point limit (typically set to 40,000), and the tie point limit (set to 4,000), which control the number of points used in the alignment process. At the end of this phase, a sparse point cloud and the camera positions are estimated;
- Georeferencing is a fundamental step in the photogrammetric workflow, enabling the absolute orientation of the 3D model. In this phase, students use either GCPs or facade points with known coordinates, typically measured with GNSS receivers or a total station, and manually mark them across the aligned images. They are instructed to mark approximately 70–80% of the provided points, ensuring an even and representative distribution across the surveyed object or area. Each point should ideally be marked in 8 to 10 images, depending on the image overlap and geometry. To ensure the reliability of the georeferencing process, a quality control procedure is introduced. Around 25% of the total points should be designated as check points, used exclusively for the independent assessment of the model's positional accuracy. The marking accuracy must be consistent with the required level of detail for each case study, typically within a few pixels for high-resolution architectural surveys. At this stage, students are also required to define the coordinate reference system, which ensures that the final outputs are georeferenced and interoperable with GIS or CAD platforms. This step not only grounds the model in real-world space but also introduces students to professional standards in survey data validation and error assessment;
- Automatic Camera Calibration is performed, estimating the internal orientation parameters of the cameras (focal length, principal point, distortion coefficients). In student exercises, an initial automatic calibration is refined based on the bundle adjustment results;
- Dense Cloud Generation from the aligned images using multi-view stereo algorithms. Parameters defined here include the quality setting (once again set from Medium to High based of the invidual PC performances) and depth filtering mode (set to Mild) to manage noise and preserve detail. After this step, manual and automatic point cloud cleaning and filtering is performed, to remove noise and to further speed up the following steps, as well as point classification to distinguish various elements;
- Mesh and 3D Model Generation from the dense cloud, with settings for surface type, face count and interpolation. This mesh is then textured to produce a photorealistic 3D model;
- DSM Generation from the dense cloud, representing all elevation features including vegetation and buildings. When needed, a Digital Terrain Model (DTM) is also produced by classifying and filtering out non-ground points;
- Orthomosaic Generation, created by projecting the aligned images onto the DSM. Parameters here include the blending mode, resolution (usually set between 1 to 5 cm/pixel based on the dimension of the object to be surveyed, the required level of detail and the PC performaces), and projection surface. The result is a georeferenced, high-resolution orthomosaic that can be used in GIS applications.

This structured approach gives students a comprehensive understanding of each phase of the SfM pipeline, reinforcing the theoretical knowledge with practical, parameter-driven processing tasks.

5. Course Seminars

In addition to technical training in photogrammetric surveying, the course also includes a series of dedicated lectures and seminars exploring the broader applications of Unmanned Aerial Systems (UAS) in various fields beyond geomatics (Figure 12).

One key area is precision agriculture, where researchers from the Department of Agricultural, Forest and Environment Science (DiSAFA) at the University of Torino described how drones equipped with multispectral or thermal sensors are used to monitor crop health, optimize irrigation, and identify pest or disease outbreaks, significantly improving resource efficiency and productivity (Grella et al., 2024).

Another focus is disaster management, particularly the role of drones in supporting firefighter operations. Through the collaboration with the regional UAS firefighting unit (*Nucleo Operativo SAPR Regione Piemonte*), students are introduced to real-case scenarios where drones are deployed for aerial reconnaissance, thermal mapping of wildfires, and rapid situational assessment in inaccessible or hazardous areas (Feliziani & Lorusso, 2023).

Finally, a compelling module is dedicated to humanitarian applications, featuring partnerships and case studies from missions in Sub-Saharan Africa, including joint efforts with UNICEF Malawi and the World Food Programme. In these contexts, drones are used for tasks such as vaccine delivery in remote regions, flood risk mapping, and monitoring infrastructure like roads or refugee camps (Calantropio et al., 2021).

These interdisciplinary lectures aim to broaden students' understanding of how UAS can serve diverse societal and environmental needs, fostering critical thinking on the ethical and operational implications of their use in complex real-world scenarios.



Figure 12. Seminars on the use of UAS for broader applications: European Laws and Regulations on the use of drones; Humanitarian applications in Malawi; Disaster Management in support of firefighting operations.

6. Final Results and Future Steps

The "*UAS for Landscape and Architectural Survey*" course has proven to be a successful and engaging teaching experience, combining theoretical foundations with extensive hands-on activities that reflect real-world workflows in geomatics, engineering, and cultural heritage documentation. By adopting a learning-by-doing approach, the course empowers students from diverse academic backgrounds to develop both technical competencies and critical thinking skills.

The interdisciplinary nature of the program also fosters collaboration and adaptability, which are increasingly vital in modern surveying, environmental monitoring, and digital documentation. In the images some of the final products of this years' teaching activities are shown (Figure 13 to 17).

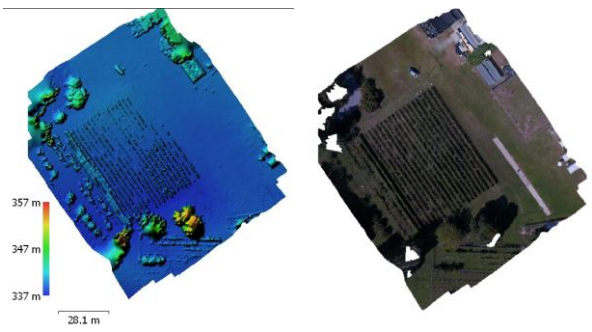

Figure 13. Final Products of a vineyard outside Torino. DSM dimensions 1'909 x 2'130 px, GSD 7.50 cm/px; Orthomosaic dimensions 7'146 x 7'972 px, GSD 2.00 cm/px.



Figure 14. Photorealistic textured 3D model of Torre Chianca in Porto Cesareo (LE). Mesh composed of 902'132 faces and 451'079 vertices.

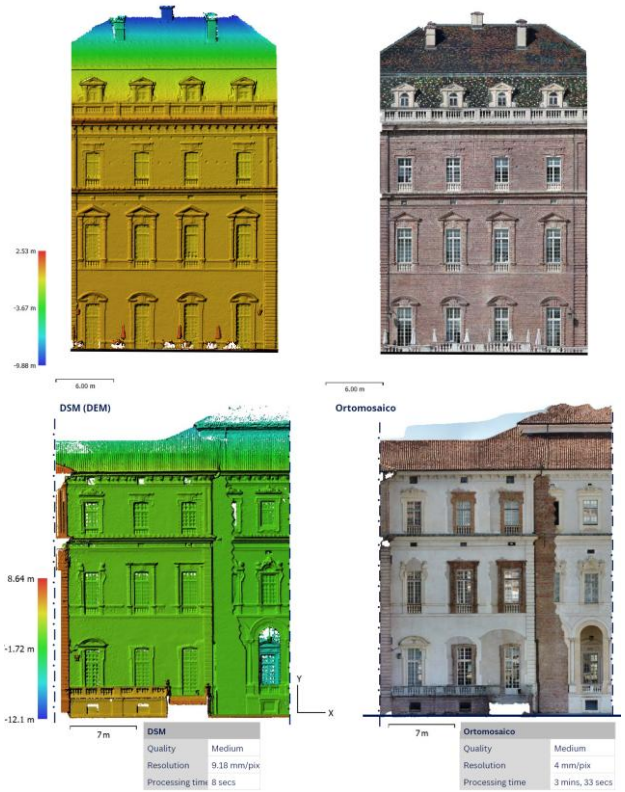

Figure 15. Final Products of two assigned portions of the Reggia di Venaria. a) DSM dimensions 1'155 x 1'558 px, GSD 2.64 cm/px; Orthomosaic dimensions 4'620 x 6'232 px, GSD 6.60 mm/px. b) DSM dimensions 1'245 x 1'742 px, GSD 2.5 cm/px; Orthomosaic dimensions 4'980 x 6'968 px, GSD 6.25 mm/px.

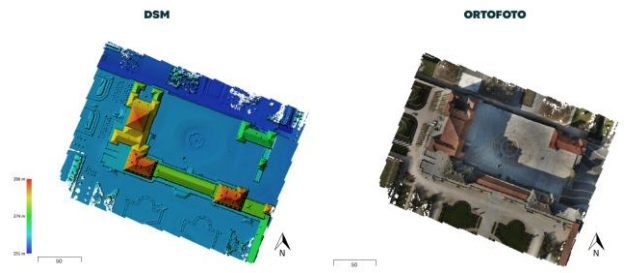

Figure 16. Final Products of the Reggia di Venaria. DSM dimensions 11'298 x 13'305 px, GSD 3.00 cm/px; Orthomosaic dimensions 16'616 x 19'928 px, GSD 2.00 cm/px

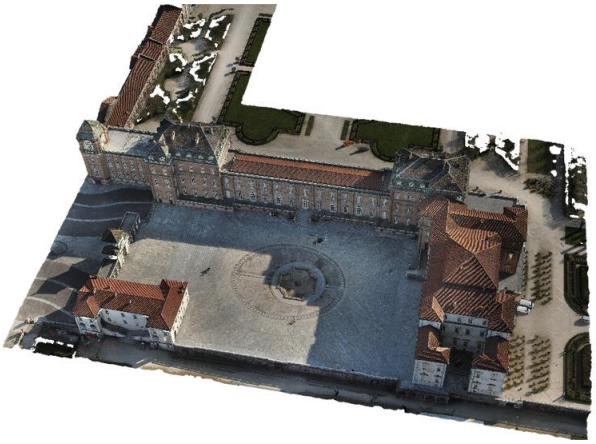

Figure 17. Photorealistic textured 3D model of the Reggia di Venaria. Mesh composed of 68'051'593 faces and 34'045'434 vertices.

Looking ahead, future improvements are being considered to further enrich the course, such as the expansion of the software toolkit to include open-source photogrammetry platforms, encouraging comparative analysis. In addition, joint projects with external institutions, such as local heritage organizations or environmental agencies, could provide students with more diverse case studies and increase the societal impact of their work.

Lastly, introducing a final student-led workshop or exhibition would enhance dissemination and communication skills, offering students the opportunity to present their work to a broader audience.

Acknowledgments

The success and richness of the "*UAS for Landscape and Architectural Survey*" course would not have been possible without the generous contribution of numerous professionals who shared their time, expertise, and experience throughout the semester. We would like to sincerely thank all the guest speakers who held seminars on the advanced applications of UAS in fields such as precision agriculture (Researcher Marco Grella from DiSAFA at UniTo), disaster response (firefighter SAPR squad, Andrea Di Lolli) and humanitarian aid (Keren Asaba, eingeneering at UNICEF Malawi), offering students a broader vision of the real-world impact of these technologies, and also to the trainer Marco Tunesi of DT Academy for deepening the European Legislation scenarios.

A special thanks goes to all the members of the "Nucleo Operativo SAPR Regione Piemonte" for their collaboration and for making their data and operational insights available for our case study, as well as the director and all the staff of the Reggia di Venaria, for allowing us to be there with the students. We are also grateful to the tutors who supported the fieldwork activities and guided students during the data acquisition and processing phases. Their professionalism and enthusiasm played a fundamental role in making this course a meaningful and rewarding learning experience for all (Figure 18).



Figure 18. Part of the 2025 class after the final examination.

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