PHOTOGRAMMETRY IN ARCHITECTURAL EDUCATION: DEPLOYING AERIAL AND TERRESTRIAL MEANS

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ABSTRACT:

Incorporating emerging surveying technologies, such as unmanned aerial vehicles (UAVs), into architectural education poses multiple challenges. This study places photogrammetry in an academic context and examines its potential impact on conventional architectural surveying methodologies. The methodology presented in this study outlines theoretical foundations and how to deploy them in the field. We taught architecture students with no experience in photogrammetry basic theoretical concepts, and we connected the theoretical framework to practical application through a case study. We considered existing methodologies suggested in the literature and their potential use in architectural education, aiming to extend architectural training to complex building surveying. For this purpose, a case study of surveying a historic building complex at the center of Athens, the Varvakeios market, is presented. The Varvakeios market was captured with aerial photogrammetry and terrestrial techniques, and a high-precision three-dimensional model was generated. The case study findings indicated that integrating photogrammetry into architectural education is viable.

1. INTRODUCTION

Photogrammetry involves acquiring precise data about tangible objects and their surroundings through photographic imagery. The photogrammetric process entails scrutinizing and construing photographic images to derive comprehensive information such as dimensions, contours, location, and alignment in a three-dimensional milieu. Photogrammetry has brought about a significant transformation in architects' approach. It enables architects to generate precise three-dimensional (3D) models of pre-existing structures, even in inaccessible locations, and facilitates the visualization and planning of architectural designs with enhanced accuracy.

The widespread dissemination of digital imaging facilitated the development of algorithms capable of orienting a sequence of images. Integrating traditional image orientation techniques in photogrammetry with a novel approach has facilitated the acquisition of precise 3D models. This integration leverages the advanced automation capabilities of computer vision, eliminating the requirement for prior knowledge while employing rigorous geometric and stochastic models developed in traditional photogrammetry. The Structure from Motion (SfM) method addresses the problem of simultaneously and automatically determining camera positioning and scene geometry. This is achieved through a Bundle Adjustment technique relying on the redundancy of information obtained from matching features in multiple overlapping and offset images.

Employing Multi-View Stereo (MVS) algorithms facilitates the augmentation of the point cloud produced through the SfM methodology. Recently, the integration of Structure-from-Motion/Multi-View Stereo (SfM/MVS) algorithms with aerial imagery has brought about a significant transformation in the field of photogrammetric surveying. This advancement has facilitated the creation of 3D models through a cost-effective, efficient, and high-fidelity approach to data acquisition and processing (Pepe and Costantino, 2020).

There has been a significant surge in the adoption of photogrammetry in architectural education. The accessibility of photogrammetry has been enhanced for professionals and students due to the availability of reasonably priced digital cameras, photogrammetry software, and hardware (Pérez Martínez and Leon Cascante, 2019). Several academic institutions, including universities and schools of architecture, have integrated photogrammetry into their educational curricula, equipping students with the essential expertise and abilities to execute photogrammetric projects.

Despite the increasing prevalence of photogrammetry in architectural practice, there exists a dearth of standardization in the pedagogical approaches employed to teach this subject matter. Several academic institutions have yet to integrate photogrammetry into their educational programs, and those that have done so exhibit varying degrees of comprehensiveness and specificity. Consequently, while architecture graduates acquire a broad spectrum of knowledge and competencies, they may lack proficiency in photogrammetry.

Besides designing new buildings, architects often have to study existing ones, especially those of historical significance. This task is part of regular professional practice. The successful execution of planning and design within the confines of a specific architectural language requires a comprehensive comprehension of contemporary construction methods, design methodologies, and national and international regulations. Additionally, it mandates a profound appreciation for architectural heritage, encompassing its historical development, origins, employed construction techniques, utilized materials, and cultural traditions, among other pertinent factors. A comprehensive building survey and research are often necessary to understand an existing architectural context (Mayer and Mitterecker, 2017).

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This study investigates architectural photogrammetry in the academic domain and examines its potential for impact on conventional architectural surveying procedures. The study centers on acquiring knowledge from teaching a cohort of novices in photogrammetry architecture students—the pedagogical applications of photogrammetry in architectural education are thus extrapolated. Students were taught basic photogrammetry principles, participated in on-site fieldwork, and were taught data processing. The course targeted creating a comprehensive raw data database, which was used to generate a precise 3D model in a field study.

The framework of architectural photogrammetry that is demonstrated here for educational purposes comprises the following two components: first, students develop the skills necessary to effectively obtain and analyze data through close-range and aerial photogrammetry techniques, and second, they acquire proficiency in 3D modeling and visualization techniques with an emphasis on generating semantically dense architectural models of buildings with historical significance.

To examine the feasibility of architectural photogrammetry in teaching, we organized a photogrammetry case study and let architecture students survey a commercial building of historical significance in Athens, Greece. The Varvakeios market, also known as the Central Municipal Market of Athens, comprises an intricate collection of historic buildings. Varvakeios has been subjected to photogrammetric analysis with drones and terrestrial photography. Using a combination of technologies (UAVs and terrestrial photogrammetry) was necessary due to the intricacy of this building complex.

2. RELATED WORK

One of the focal points of contemporary architectural education revolves around comprehensively understanding and introducing photogrammetric technologies in architecture (Shults, 2019). In the past, architects and surveyors exclusively relied on analogue paper-based methods. In contemporary times, there has been a notable advancement in new technologies, leading to extensive adoption of new tools by professional architects and engineers for data collection and digital model generation. Nevertheless, there is a significant delay in integrating these techniques into educational curricula. Many efforts to incorporate surveying methodologies into the pedagogy of tertiary architectural education are presented in the literature.

Shults (2019) suggests an architectural photogrammetry course to educate and train architects and scientists. The course familiarizes the students with the technologies and enables them to address various practical architectural and engineering challenges through photogrammetry techniques. The course includes five components. It commences with a concise overview of photogrammetry, followed by an exposition of fundamental concepts. Subsequently, the equipment involved is examined, like UAVs and terrestrial laser scanning. The course culminates with the implementation of photogrammetric fieldwork, involving data acquisition, organization, importing, exporting, and integrating the collected data.

Kravchenko et al. (2016) present a collaborative educational initiative by the Institute of Applied Sciences at Jade University Oldenburg, Germany, and Kyiv National University of Construction and Architecture in Kyiv, Ukraine. This project aimed to implement terrestrial laser scanning technology and close-range photogrammetry to gather and analyze spatial data. The implementation of this project has led to the development of practical recommendations for organizing educational processes using terrestrial laser scanning. A 3D model depicting the expansive and intricate campus of Kyiv National University of Construction and Architecture was generated to ascertain the efficacy of the technology.

Tucci et al. (2018) contend that the learning-by-doing method is more effective in teaching photogrammetry in various non-specialist courses. Instead of a traditional lecturing method, they propose disseminating knowledge among individuals already using it without a comprehensive understanding of its principles. By adopting this hands-on approach, students focus on maximizing quality and evaluating precision through practical application in real-life case studies. Hence, instead of the conventional didactic model, this methodology transitions to an approach in which students actively enhance their skills by engaging in practical problem-solving. This educational experience prompts students to reassess and gain a deeper understanding of the various stages of designing, acquiring, and processing a survey project. Furthermore, it enables them to develop enhanced abilities in critically evaluating the collected data.

Salagean-Mohora et al. (2023) propose a teaching method using photogrammetry for architectural documentation. Their approach establishes a cohesive connection between theoretical education and architectural restoration. The study has two stages: an educational, experimental workshop and an architectural restoration application. After knowledge acquisition, experimentation, and refinement of the close-range photogrammetry data, the authors and students implemented the most effective methods for restoring facades. The authors contend that student observation must be extended over longer periods to maintain the significance and consistency of the research. Comparing students' work to their peers with similar backgrounds reveals the level of their technology proficiency.

Chapinal-Heras et al. (2023) examine the potential for instructing students on the materiality of small-scale historical artifacts and provide training on creating 3D models using various techniques and software applications. The authors posit that the advantages of engaging in this activity are rooted in attaining a more intimate and profound connection with the material culture. While acquiring proficiency in 3D modeling, students are exposed to the artifacts' historical context, significance, and utilitarian aspects and develop an understanding of the cultural significance associated with these objects.

Baik and Alitany (2018) examine the feasibility of employing a documentation approach for heritage buildings in Historic Jeddah, Saudi Arabia. Their case study uses architectural photogrammetry to explore this technique's potential in the digital architectural heritage field. The authors contend that the efficacy of photogrammetric technologies in enhancing education is limited when considered in isolation from the rest of the curriculum and highlight the importance of integrating these technologies within an inclusive educational framework.

Tucci et al. (2020) present a 2018 ISPRS Capacity Building Initiatives project focused on "Education and training resources on digital photogrammetry." Their findings indicate that incorporating educational resources and using intelligent teaching methods are essential in promoting the widespread use of photogrammetry among diverse populations. Their studies demonstrate the efficacy of integrated educational approaches bolstered by engaging instructional resources, such as tutorials, guidelines, videos, and datasets. Various teaching and learning methods are implemented to facilitate capacity development among professionals, educators, and students. These approaches aim to enhance effectiveness and support distance learning programs. The students gain practical skills in photogrammetry and an understanding of the underlying theoretical principles. The suggested pedagogical approach and instructional resources demonstrate efficacy in hands-on experiential learning and remote online education.

Mayer and Mitterecker (2017) outline a surveying workflow that aligns with the needs of architecture students. It allows students to learn firsthand surveying techniques and concepts while focusing on their primary objectives without being overwhelmed by excessive technical intricacies. By acquiring this knowledge, prospective architects could be better equipped to estimate and assess survey expenses and outcomes. The authors claim that it is imperative to maintain a low student-to-teacher ratio to ensure knowledge transmission and uphold the quality of instruction and academic outcomes at the highest possible level. The acquisition of practical experience remains the most effective learning method and should be augmented across all domains within architecture.

Hence, integrating drone technology into architectural education can enhance student motivation and engagement (Rábago and Portuguez-Castro, 2023). Engaging students in experiential activities that may involve drone technology fosters their interest and introduces an element of enjoyment, thereby facilitating learning within a positive and conducive environment (Sattar et al., 2017).

3. ARCHITECTURAL PHOTOGRAMMETRY IN EDUCATION

This presentation covers the content of a course taught in the Fall of 2022 at the graduate program of the School of Architecture of the National Technical University of Athens, Greece. The focus was teaching students with no prior knowledge of the theoretical and practical aspects of photography, UAVs, and photogrammetry, by providing knowledge on specific concepts and deploying this knowledge in the field in a hands-on case study. The case study included surveying a historical building complex, the Athens Central Municipal Market.

Figure 1. Aerial view of Varvakeios market and the surrounding area.

3.1 Case study

The Varvakeios market is the Central Municipal Market of Athens (Figure 1). It occupies the area delineated by the streets of Euripidou, Aiolou, Sophocleous, and Athenas. The erection of the Municipal Market complex was initiated by the Municipality of Athens in 1878, gradually taking shape in the eastern region of Varvakeion (National Hellenic Research Foundation, 2023). Nonetheless, a fire on August 8-9, 1884, impeded progress, as it destroyed the buildings of the Old Agora situated east of Hadrian's Library that was still operational. The construction on Athena Street was expedited, culminating in the New Market (Agora) completion in 1886. Since then, the establishment has been uninterrupted, always accommodating food vendors. From 1979 to 1996, and while it was still in operation, the building underwent a gradual restoration funded by the Municipality of Athens and the Greek Ministry of Culture.

Figure 2. Varvakeios interior view of the seafood market.

The designer of the building was Ioannis Koumelis, who was inspired by analogous buildings in European urban centers. The building has a characteristic orthogonal plan. Presently, it accommodates an organized marketplace wherein numerous vendors of regionally sourced commodities, including meat, poultry, seafood (Figure 2), and agricultural produce, are situated. The structure is regarded as a significant architectural landmark to cater to the demands of both the local populace of Athens and tourists (Greek Tourism Sector, 2023). It is open every day, except Sunday, from early morning till late afternoon.

3.2 Data acquisition

Deploying the course's theoretical component in a hands-on case study comprises all the typical phases of an architectural survey project. The procedure consists of three stages:

1. The formulation of a strategic plan for documentation and image acquisition
2. The execution of field operations
3. The analysis of the acquired data using photogrammetry software.

A field methodology primarily relies on the existing human and technical capabilities and limitations, as well as those imposed by observational factors (Teza et al., 2016). Our study was conducted within an educational context involving architecture students inexperienced with aerial or terrestrial photogrammetric techniques.

An essential component of the process was planning mandatory field visits to optimize the outcome within the given time and

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resources (Figure 3). A comprehensive plan was proposed, outlining the placements of each photograph and the requisite camera angles, considering the necessary overlap for capturing the buildings. The students generated an accurate flight plan for the UAVs deployed in the field. Then, the drones, cameras, and geolocation configurations were established, and the scale bars were duly positioned.

Figure 3. Field visit.

Selecting the appropriate time of the day to initiate flight operations is crucial in using a UAV to generate a 3D model. In addition to mitigating the effects of strong winds and precipitation, selecting a moderately overcast day during the midday hours is necessary. Hence, the shadows need to be neither excessively pronounced nor elongated.
Based on Moe et al. (2016), oblique mapping is the predominant technology for data acquisition in 3D reconstruction. Combined with an orthogonal aerial survey, the oblique survey provides distinct data, including complete information on facades, delineating units without obstructions, and yielding details about floors and roofs (Silva da Purificação et al., 2022).

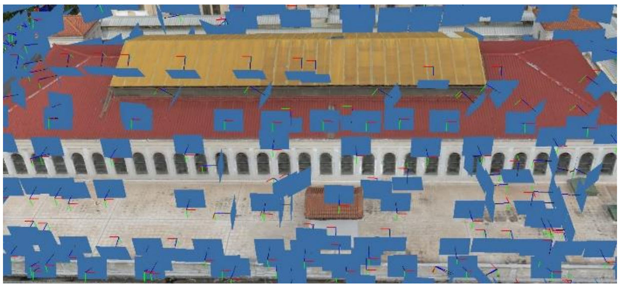

Figure 4. Projection centers at ground level, by the UAV camera.

Our methodology included flights at preselected altitudes and trajectories covering distinct building characteristics. The inaugural flight occurred with the drone's camera positioned in a nadir configuration. Successively, a series of orbital missions were conducted, encompassing varying altitudes and camera perspectives (oblique), to enhance the overall fidelity of the resultant model (Figure 4). A total of five field visits were necessary to collect the data. To reconstruct facade features, images were also shot from the ground using a tripod in addition to the flights. Because the building is situated in an urban environment with a high density of people and to better acquaint the students with drone piloting, all the flight plans were handled manually, not automatically.

We used DJI Mini 3 Pro (DJI, 2023) drones and, for the terrestrial shooting, a Sony Mirrorless α6000 with a full frame lens. The DJI Mavic Mini 3 Pro (Table 1) was chosen over previous versions due to its superior image quality and ability to adjust the camera's inclination, thereby enabling to capture previously imperceptible elements in digital photographs. The camera's vertical axis rotation – enabling a downward reach of 90 degrees and an upward reach of 60 degrees – facilitated the capture of photographs from a bottom-up perspective.

Sensor	Type	CMOS
	Dimension	1/1.3”
Lens	FOV	82.1°
	Aperture	f/1.7
Resolution	4:3	8064 × 6048
Proximity sensors		Yes

Table 1. DJI Mini 3 Pro specs.

3.3 Data processing

A significant recent development is the integration of digital photogrammetry and computer vision in software applications designed for the automated generation of 3D models through digital images (Achille et al., 2015). A software application was used in our study, the image post-processing package Metashape Professional v 1.8, developed by Agisoft (Agisoft LLC, 2022). The orientation procedure of the photogrammetric datasets included digital images that met the highest quality criteria.

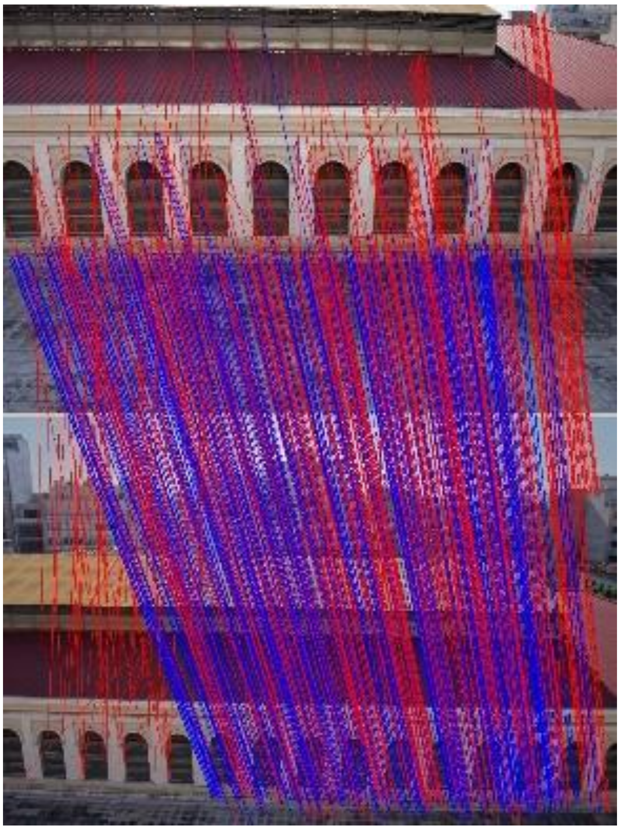

Figure 5. Example of matching pairs (blue: trustworthy vs. red: untrustworthy).

The dataset, containing 1390 images, was processed in self-calibration mode. After selecting the digital images, masks were used to restrict the regions of the original images, which would undergo analysis in Metashape. Following the photogrammetric pipeline of Metashape, the dataset was aligned by employing the self-calibrating Bundle Adjustment technique and the feature-based approach.

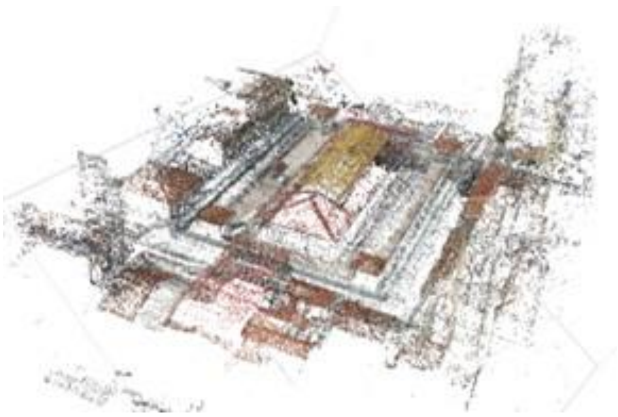

Figure 6. Tie points are recognized after the alignment.

Photogrammetric data do not necessitate specific targets in the scene. Instead, they generate a list of matching pairs by leveraging identifiable natural points and geometries as features (Figure 5). Following the alignment process, the tie points dataset (Figure 6) underwent a filtering procedure considering factors such as reconstruction uncertainty, projection accuracy, and reprojection error. The process continued by clearing out the unnecessary points and defining the limits of the area of interest. Scale bars were used to assess the accuracy of image matching. The students considered the number of projections and the resulting error, generating a dense point cloud.

4. RESULTS

A dense 3D point cloud was generated, comprising 150 million points. Based on the processing report produced by the software, the Market model exhibited an overall geometric accuracy of 2.26 cm. It should be noted that the comprehensive coverage of all sections of the Market model required 1.312 images. The 3D textured mesh model consisted of 40 million triangular faces. Figures 7, 8, and 9 display the 3D model of the Market. The reprojection error was 0.54 pixels, and the final ground resolution of the images, given the distance between the camera stations and the Market, was 5.46 mm/pix.

Figure 7. 3D model, top view of the Market.

Finally, a report was generated, consolidating the essential information about the process and the model, including details and data. The report increased the accessibility and comprehension of the underlying process for educational purposes. This final stage improved the understanding of the project within the context of architectural education, namely the development of an academic curriculum around the theoretical and practical aspects of photogrammetry.

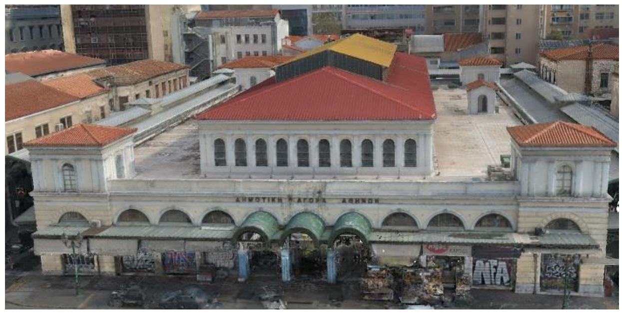

Figure 8. 3D model, front view of the Market.

Figure 9. 3D model, side view of the Market terrace.

5. CONCLUSIONS

A pedagogical approach was outlined to introduce students to digital photogrammetry and enable them to participate effectively in architectural surveying projects. The suggested methodology generates architectural 3D models for documenting building interiors, exteriors, and complexes, offering valuable practical and educational insights. It has numerous technical advantages, such as accuracy, generation of semantically rich models, and optimization of time and resources. The overall experience teaching graduate architecture students without prior exposure to photogrammetric technologies was positive. Students were enthusiastic about the method and were driven to learn more about the basic principles, use of the photogrammetry tools in the field, and apply them in a case study. The results of this study demonstrated the feasibility of constructing a precise 3D model of a historic building, the Central Municipal Market of Athens, which was quite complex and not readily amenable to terrestrial surveying. The project was successfully completed within one academic semester, in only five 2-hour field visits and while in parallel we taught the students the basic theoretical principles and hands-on applications of aerial and terrestrial photogrammetric data acquisition technologies and the data processing software. Some immediate pedagogical observations are that photogrammetry sharpens the students' critical thinking and problem-solving skills and renews students' interest in cultural heritage. It trains students to plan effective strategies, be effective in the field, and analyze, interpret, and process data. Photogrammetry offers significant aids in architectural heritage research by renewing student interest in comprehensive examination and understanding of historic buildings. By providing novel visual experiences, it makes architectural heritage accessible to both experts and non-experts. Finally, from a technical point of view, since photogrammetry outputs highly accurate models that can be used for multiple purposes, it will likely become part of standard architectural practice and education in the coming years.

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