TRAINING STUDENTS IN GETTING ARCHITECTURAL KNOWLEDGE FROM SMARTPHONE-BASED PHOTOGRAMMETRY: THE FIREPLACES BY ANDREA PALLADIO

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ABSTRACT:

Since 2021, the *Centro Internazionale di Studi di Architettura Andrea Palladio* (CISAAP) in Vicenza and the *Department of Architecture at the University of Bologna* collaborated for a didactical joint initiative involving students from the *Photogrammetry for Architecture* course. The main goal was to develop a new teaching approach for architectural education exploiting photogrammetry as a digital tool for joining the Architectural Heritage (AH) documentation with the architecture analysis and design interpretation. Beginning from the new technological advances (semi-automatic workflows and smartphone cameras use), a 'learning-by-doing' didactical method and situated real work problems, a whole systematic process, based on the concept of a digital copy of an architectural artifact as mean to collect and to aggregate knowledge, was developed and inferred to the student. Starting from the designed teaching path, in which the perspectives of the historian, the surveyor, and the designer are blended to get a holistic vision of the architecture, 29 fireplaces by Andrea Palladio were chosen as emblematic case studies. These microarchitectures let students understand the complexities of historic objects and of their digitalization to produce 3D models as outcomes of an acquisition pipeline useful to train them for a future professional career.

1. INTRODUCTION

The *'measure and draw'* was the main activity in the architect training since - as Giorgio Vasari quotes (1568) - Brunelleschi and Donatello, during a trip to Rome in 1405, firstly conducted surveys and took notes as an integral part of their visit to the ruins, to analyze and understand features and elements of the ancient Roman architecture. Vasari's narration already brings the clear core of the survey discipline, which can be defined by two words: *measure* and *draw*, namely, to take a measurement and to reproduce it in the draw phase where it was taken. Furthermore, he introduces the purpose of the surveying activity: to provide architects with knowledge of the architectural space as a mixture of shape, function, and construction with the aim to use this knowledge as a design technique. From the description emerges how surveying and learning were integrated activities which constituted the foundation of the architect's work.
Over time, surveying techniques progressively evolved thanks to the comparison with architectural materials to be acquired and known, so that architectural surveying did not remain a technique for determining proportions and features of ancient architecture as a whole and as individual parts, or the report of orthogonal views of the artefacts "[...] *dessinés et mesurés très exactement*" (Quatremère de Quincy, 1832). As specified by the ICOMOS in 1996: "*Recording is the capture of information which describes the physical configuration, condition and use of monuments, groups of buildings and sites, at points in time and it is an essential part of the conservation process*".
This definition has remained the reference up to the present day with the sole introduction of the use of 3D models instead of 2D plots, thanks to the strong push by Information Technologies (IT) techniques and a new workflow starting from reality capture (3D scanning and photogrammetry) to reality computing (3D modeling and data management), and reality creation (VR, AR and 3D printing).
From a didactical and knowledge organization perspective, however, this progressive specification and articulation of methods, techniques, and contents, has been matched by a progressive separation of survey and architecture, which have become autonomous disciplines with different characters (when their strength was in their complementarity and supplementary nature). The former is today based on numerical and deductive methods while the latter on figurative and inductive ones.
The effect of this separation is that our digital AH and CH world is still far less real than what it tries to document, and the education of the architects and architect-engineers is challenging. Mainly, it has been completely forgotten the didactical system that allowed to architects to learn the features of ancient architecture leading, even in the field of the construction arts, to the development of the Renaissance architecture. The learning-by-doing approach, which today we rediscovered thanks to the deepening and revisiting of John Dewey ideas, remained longtime a secondary learning technique. It was forgotten that knowledge cannot be acquired without practice, and that action boosts the development of ideas, which are what let us organize our future experiences and observations, and therefore the architectural project.
In this paper, we describe the didactic structure, the teaching methods, and the outcomes of a project carried out between the *Centro Internazionale di Studi di Architettura Andrea Palladio* (CISAAP) in Vicenza and the Department of Architecture at the *Alma Mater Studiorum - University of Bologna,* as joint initiative to foster a complete multidisciplinary experience for students involved in the *Photogrammetry for Architecture* course.
Since 1958, the CISAAP is one of the most important research institutes for the history of architecture worldwide. The research activity at the Centro, which is coordinated by a panel of some of the finest specialists in the field, includes exhibitions, courses, seminars, and workshops dedicated to the architect Andrea Palladio (1508-1580) (Beltramini and Burns, 2008, Puppi and Battilotti, 2008), modern and contemporary architecture as well as the conservation of historic structures. During its more than fifty years of activity, the CISAAP has collected and developed a great documentary archive with the most important treatises on

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architecture from the XVI to the XIX century, over 16,000 photographs providing extensive documentation of the Palladio works, the “*Corpus dei rilievi delle fabbriche palladiane*”, published with the support of the Italian National Research Council by the CISAAP in the years 1960-1970, representing the remaining 49 buildings of Andrea Palladio; maquettes of most Palladio’s projects; 3D digital models of most of the built Palladian architectures.

The course at the University of Bologna is meant to prepare attendants in the construction of 3D digital models of AH, adopting photogrammetric techniques. Students were instructed to design a photogrammetric survey, to perform it, to build reality-based 3D models, and to prepare them for the typical uses of design processes: analysis, design, management, and communication.

In this context, Palladio’s architecture and Palladian drawings and texts are an extraordinary field of experimentation with their clear design thinking and their measurable and observable solutions. They provide a detailed language of architectural form, a specification through formal grammars, an easy interpretation, and a specific role in structuring design. It is possible not only to observe specific Palladio’s architecture but to reexamine central issues of architectural design theory, giving a comprehensive and systematic treatment to the logical foundations of design thinking. Specifically, Andrea Palladio’s work is a paradigmatic case, introducing all problems related to the use of 3D modeling for survey, analysis, reconstruction, interpretation of AH, and an excellent starting point to develop a teaching method for new techniques and new knowledge (Gaiani, 2019).

The collaboration project here introduced combines a series of distinct interests: the need for research on architecture, the application of cutting-edge scientific procedures and tools in the field of the architectural survey, and the training of students in the use of these tools to deal with the built reality. Three different points of view, that of the architecture historian (the expert of the buildings design, construction, and evolution history), that of the surveyor (the expert in reality-based 3D models construction) and that of the designer (aiming to know the past and the present state of the artefact to design its future) are combined into a common methodological and didactic approach. Its goal was to develop an integrated ‘learning-by-doing’ approach, fundamental in the case of digital photogrammetry because its knowledge cannot be divided from the user’s ability to handle specific software. The joint project represents, then, a deepening of technical skills, an occasion of knowledge on architectural principles and design traditions, and an on the field experience.

This didactical structure exploits a broad definition of the photogrammetry term. It is “*the art, science and technology of obtaining reliable information about physical objects and the environment through processes of recording measuring and interpreting images and patterns of electromagnetic radiant energy and other phenomena*” (ASPRS).

A key point in the experience concerns the use of smartphone-based automatic photogrammetry as key technology for the 3D data capture and model construction (Kingsland, 2020). Due to its economic affordability, when compared to other remote sensing techniques (e.g., 3-D scanners), a parallel development of photogrammetric software allowing a increasing ease to use in producing 3D models photogrammetry shows a high level of acceptance among non-expert users and offers a great educational opportunity to students too, especially if they are involved in fields related to architecture (Stathopoulou et al., 2019). In recent times, the quick development of the smartphone cameras, making smartphones privileged devices for automatic photogrammetry and for its learning, due to their versatility, their diffusion among students and the relative ease of use (Cardinal, 2020).

This paper describes how the designed learning process, combined to easy, accessible tools, is paramount in the architecture area education of future professionals.

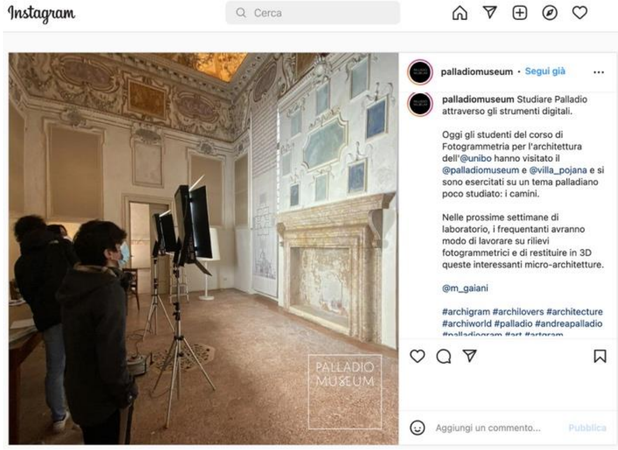

Figure 1. Survey activities by students as documented on the social network *Instagram*, from a post published on the official *Palladio Museum*’s profile.

2. THE DIDACTIC PERSPECTIVE

2.1 The state of the art

Still at the end of the last century, photogrammetry teaching and learning was based on three distinct and separated moments: theory, exercises, and project. Focus was mainly on the changes related to the introduction of computing-based techniques (e.g., “*The reconstruction of the object is carried out by means of the computer only*” (Höhle, 1997) and in the improvement of digital methods learning, both not obvious operations because the low-level of IT-related skills of the students at the time. Even if some pedagogical principles were introduced, these were extremely limited, concerning, e.g., the subdivision of knowledge in small for an easier presentation and comprehension; integration of fun and play; the questions and exercises inclusion in the frontal lesson method.

Ten years later, while the introduction of digital principles next to the analog one and the software training were still the focus, first attempts of interactive teaching were introduced (i.e., the information communication using computer supported presentation, as well as the transmission of didactical materials through Internet in the form of e-learning). Furthermore, e-learning principles and techniques and 3D based approaches appeared (Ruzgienė, 2008). Anyway, the traditional teaching method based on theoretical presentations (in oral or written forms) and practical units for the software training in basic photogrammetric workflow remain the usual solution.

But it was in the middle of the first decade of this millennium that in the photogrammetry teaching and learning appeared new didactical concepts able to replace or at least complement the traditional lectures-based manners: ‘problem-based learning’ ‘project-organized learning’, ‘progressive inquiry’, ‘integrated micro learning’, ‘narrations’, storytelling. as tools (Höhle, 2006; Gomes Pereira et al., 2004) and more in general a didactical system grounded on the ‘learning-by-doing’.

The availability of low cost of devices and the development of highly automated procedures for orientation and dense image matching (ensuring satisfactory automation, efficient results and ease of use, even for non-professional, mainly in the fields related with the CH) empowered in the last decade a quick democratization of photogrammetry leading to the definition by Stuart Granshaw ‘mass photogrammetry’ (2015): by exploiting these techniques users have become producers of their own digital 3-D contents (Tucci et al., 2018). Under the boost of new didactical concepts from the previous decade, and of this great great popularization of the photogrammetry, in the last ten years many didactical applications were developed, to infer the knowledge needed to recognize their effectiveness and nature. Overall, this new scenario requires a strong change in the educational processes that cannot be limited to a simple shifting of which knowledge is taught. Instructive systems have been made available, like Arpenteur (Gussenmayer and Drap, 2001), a web application for architectural photogrammetry, and PhoX developed to provide self-learning tools, tests, and exercises with real photogrammetric data with the aim to allow practice with data analysis, interactive image measurements, simulation, and visualization of results (Luhmann, 2016). An author of this paper was part of the GRAPHOS project (González-Aguilera et al., 2016), a software development aiming to deliver a free tool able to provide an educational, easy-to-use, and ease-to-learn framework for image-based 3D reconstruction applied to AH, CH, architecture, and engineering applications. With the goal to avoid the use of the new low-cost automated solutions as a 'black box' by its large audience of non-specialized users as the architects and the CH operators, GRAPHOS project, supported by an ISPRS Scientific Initiative, realized an all-purpose open-source photogrammetric platform. A central feature of the system was its setup as a tool to implement learning-by-doing didactical techniques.

In the last years, many experiences focused on the 'in situ' training as the "Laboratory of Places, Ghesc and surroundings, history, survey, evolution" organized by the 3DSurvey Group at the Politecnico di Milano (Achille et al., 2018) and sponsored by ISPRS society. This annual summer school program aims at the learning of the primary disciplines and methods linked to the analysis of CH and the accomplishment of capabilities acquired through the practical on-field experience. Other projects aims to exploit practical experiences to teach photogrammetry for students of the courses in the degree of Architecture, integrating these activities into their curriculum, as the "Representation techniques using methods of Photogrammetry" at the Politehnica University of Timisoara (UPT) in Romania (Salagean-Mohora et al., 2023) with the aims to make accessible to the student 3D-based techniques instead of 2D drafting, bringing to students an observational method able to get a quicker and wider knowledge of AH and its features. If just basic uses of the 'learning-by-doing' and 'e-learning' concepts were introduced in these experiences (sometimes with excellent results), other experiences investigated more sophisticated and innovative pedagogical strategies that we can relate to *smart education* methods (Shi et al., 2019). In these cases, too, AH and CH were main fields of application, probably because of their nature to be subjects to the the development of 'measure and draw' original techniques (Kravchenko et al., 2016). Works such as those by Bonacini et al. (2015) and Baloğlu et al. (2018) already introduced efforts to train university/high school students to the basic competences in the use of photogrammetry in collaborative CH projects.

Finally, other research coupled the new didactical techniques with the use of personal devices (i.e., smartphones) as survey tools. Among those emerges the D3Mobile project, a fully online competition for worldwide participants funded by the ISPRS and based on the project-based e-learning approach. The aim for participants is to obtain reality-based 3-D models using their own mobile phones and to critically examine the metric accuracy of results (Ortiz-Sanz et al., 2021). Even though the project is not specifically inscribed in the architecture or AH area (the goal is to check the potentials of smartphones as accurate measurement devices, a typical STEM problem), it shows the capabilities of the joint use of personal devices and project-based learning didactical techniques, the same approach followed in our project.

2.2 The methodological approach

The didactic activity of our project was based on an active approach, having the learning-by-doing principle as general guide. More specifically, because learners act as stakeholders in built environment education, as underlined by other authors (Various Authors, 2019; Reich, 2010), an interactionist-constructivist pedagogical approach is particularly appropriate to describe learning processes. It assumes as central dimension the active participation of the student in the learning and therefore the construction of the meanings from experience. This is the aim of the New European Bauhaus initiative launched by the European Commission (New European Bauhaus, 2020) for the architecture learning area, where teaching combines theory with practice to develop students' observational, analytical, and thinking skills. Students and teachers worked in groups to identify problems, to find solutions, and to seek immediate feedback from industry to refine their design approach.

More in detail, the didactic architecture used in our project, is based on the four predominant strategies of instruction proposed by Ruth Colvin Clark (1998). Here Instructional Architectures provides a taxonomy that can be used to consider different strategic approaches for meeting varying human cognitive and performance task needs. In detail, we based on the variation proposed by Antonio Calvani (Calvani, 2017), where two further instructional architectures were added to those proposed by Clarke: receptive, directive, guided discovery, exploratory). The italian pedagosist added the collaborative architecture and separated the simulation dimension from the guided discovery architecture (Tab. 1). As the author notes the simulation is not, strictly speaking, entirely referable to the guided discovery.

Education architecture	Distinguishing factors	Didactic formats
Receptive (transmissible)	• Control by teacher/system • High information pre-organization • Lack of or scarce interaction	• Lesson • Classic explanatory lesson • Anticipating lesson • Narrative Lesson
Behavioural (directive-interactive)	• Control by teacher/system • High information pre-organization • Strong interaction	• Tutorial approach • Programmed education • Modeling/guided practice
Guided discovery	• Shared control by teacher/student • Partial pre-organization • Strong interaction	• Problem solving • Problem based learning • Socratic method • Heuristic lesson
Simulative	• Control by student • Model or information pre-organization • Strong interaction (with model/system)	• Simulation • Symbolic simulation • Simulation from experience • Role playing • Case study
Collaborative	• Control by student • Greater/Smaller pre-organization of tasks and organizational structure • Strong interaction among peers	• Group learning • Reciprocal support • Collaboration/Cooperation
Explorative	• Control by student • Lack of or scarce information pre-organization • Scarce interaction	• Independent expression • Project, research • Brain storming, free individual expression

Table 1. Didactic architectures and formats.

In our work, two architectures were used: the 'Guided Discovery Architecture' as primary method, and the 'Collaborative' one as secondary. The 'Guided Discovery Architecture' is based on learning through problem solving and a facilitated discovery, then resources are provided to support the active construction of knowledge. When learning is situated in a realistic work problem ('Situated Guided Discovery Architectures') the role of the instruction is to provide resources and experiences that promote the internal construction of new knowledge and skills. Compared to the behavioral architectures, the guided discovery approaches emphasize the construction of unique knowledge bases instead of consistent acquisition of predetermined knowledge and skill hierarchies (Phillips, 1995). The architecture is more efficient with students 'experts', as those of the last years of the degree, i.e., our case. The level of learner control is substantially higher, enabling the participant to access a wide range of tools and guidance to address the issue. Feedback often tries to simulate the actual outcomes of actions taken in the real world rather than focusing on right or wrong. Moreover, collaborative learning in small group settings is being stressed more frequently.

'Collaborative architecture' is about learning with peer interaction, including various forms of mutual teaching and teamwork. Collaborative activities in the classroom are important both on a cognitive level, allowing students to critically compare different points of view and on a relational level, learning to interact, respecting common rules. In our case, the survey and knowledge of fireplaces forced students to face real working problems. In this didactic strategy the case studies provide real simulation contexts, capable of making people skilled of acquire efficiently, and in a short time, knowledge and know-how strictly addressed to the professional profile to be trained. The students had to learn how to operate in places very different from the lab (fireplaces are in Villas widespread over the Veneto's countryside) and they had a well-established and short time to finish the work (the access time to the assigned fireplace was limited to one working day), without the chance of check the results at home and of a second visit to the repeat the wrong tasks (this lead to a real-time and on-field control of results). Also, commodities were very scarce since Villas are often inhabited and closed, with no electricity or heating (i.e., the survey was carried out between the second half of October and the beginning of November). It was therefore a very challenging learning environment in which the traditional survey design problems (definition of the camera network, the characteristics of the images to be acquired, the technique of maintaining color fidelity and metric accuracy), and data acquisition were accompanied by other typical of a real context. This approach fills the observation by the pedagogical disciplines that 'practice' is not the simple application of a theory so that such theory cannot be often applied to cases for which it was created. The theory converges directly into the knowledge behind the act in practice, but not into the expert practice to which it is belonging, e.g., to the engineer, who operates not because he directly applies a theory, but in relation to what he expects to be the result, i.e., to his knowledge of the practice. Therefore, what it is possible to learn from the learning-by-doing in real case study is not only practice, but expert practice, i.e., the practice of the expert (the expertise), which is certainly an apparatus nourished by theory, but it is not just an application of theory nor a simple knowledge, but a more complex way of knowing how to see and how to act.

Other didactical features of our project come from previous experiences, mainly a series of courses designed and carried out for the Scuola Normale Superiore di Pisa from 1997 to 2011 (Benedetti et al., 2021):

- Integration of knowledge from different fields (geomatics, representation, history of architecture, restauration) in a multidisciplinary approach. It involved the co-presence of various actors who worked collaboratively: thus, the teaching was held by groups.
- Inclusion of the IT as an operation tool.
- Reconstruction of real case studies showing both theoretical and practical aspects, framing the entire 'lifecycle' of the AH.
- The proposed integration concerns not only theory and expert practice but also knowledge and know-how. To this end, the workshops become the exercise testbed for the skills illustrated through case studies.
- Software-based learning lessons providing more than a list of software commands or specific tutorials: they fostered a critical analysis of the 3D model-based photogrammetric workflow based on an accurate reinterpretation of Palladio's architecture features to better understand how to translate these elements into a digital form.
- Development of specific skills, supplemented by transversal ones, capable of nourishing the specialized ones, to build differentiated and broad-spectrum real cases.

3. THE PALLADIO'S FIREPLACES

Andrea Palladio was certainly the most influential and best known of Renaissance architects. Reasons are easily identifiable in a wide production (over 54 sites including villas, palaces, public buildings, churches and bridges); in his ability to innovate architecture and inscribe it in an easily understandable language thanks to evident stylistic elements and morphemes; in a well-defined structure allowing to understanding architecture set out in a widely circulated text (The *Four books of the architecture* first published in Venice in 1570, but with countless reprints and translations) (Palladio, 1570) and providing an easily replicable system in space and time with few variations linked merely to regional instances. Palladio's ability to represent a complex and articulated technique of architecture design and construction using few simple graphic schemes, was the key to his success and the means that allowed him to produce such a wide and articulated production.

Because of this centrality of a design method by representation through simple and clear schemes, the topics arising from observation of the Palladian system are the finest themes through which it is easy to explain the 'making architecture', the methods and the techniques leading to the building construction and to the investigation of its current state (i.e., the survey). This is especially true today, when digital and numerical-based systems have changed the relationship between the object of representation, its meanings, and the designer mind in a process of increasing virtualization.

Palladian buildings, drawings and texts provide a detailed language of architectural form and an easy interpretation of their measurable and observable solutions allowing an easy understanding of their design and of how they were conceived. This clear system is then an extraordinary field of research to experiment new methods, workflow and techniques, as evidenced by the interest on the Palladio's work in the early days of computer graphics and information digitization, whose renowned paper by William Mitchell and George Stiny *The Palladian Grammar* (1978) is surely one of the most notable examples. Alongside this primary driver, a second reason led us to select Palladian architecture as the subject on which to experiment new instructional strategies for teaching photogrammetric techniques.

The study of Andrea Palladio's work was historically carried out on abstract considerations inferred from the analysis of his treatise and the subsequent re-editions and publications. Only in recent decades the direct study of built Palladian architecture has become, once again, an important matter of study that cannot ignore the availability of accurate scientific surveys.

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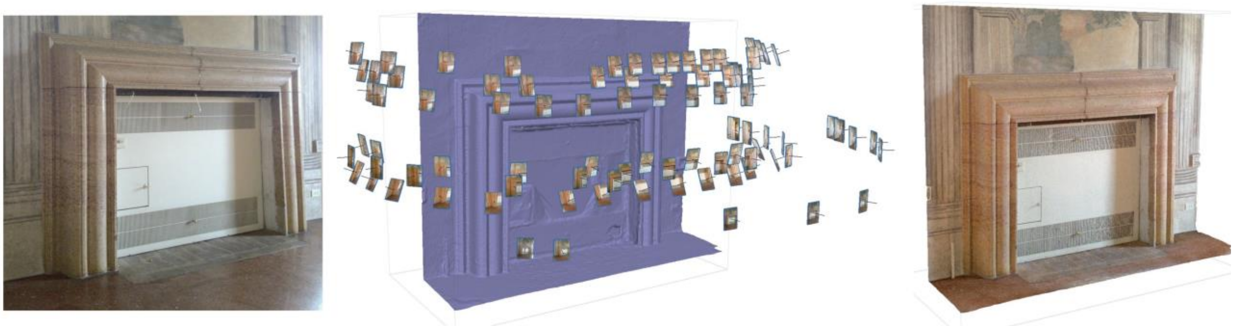

Figure 2. A fireplace by Andrea Palladio in Villa Pojana, Vicenza: the original artefact (left image), the camera network (center), and the fully textured 3D model (right) (3D model by Luca Ballestri and Carmen Mazzella).

As specific subject we focused on the fireplaces, objects mostly unconsidered by the historiography apart from their decorative apparatus, becomes relevant, as document a subject with an extremely limited number of studies. The fireplaces, in fact, are perfectly accomplished microarchitectures. They consist of the basic building elements: two piers supporting an architrave. However, these three elements are often declined in different ways. They can be a scaled replica of an entablature system on pillars or shelves, or they can be a continuous frame around the fireplace. The survey of their moldings, which are different for each fireplace as they represent the "*fingerprint*" and the gimmick to model the *chiaroscuro* through the material, let scholars and researchers to deepen a completely neglected theme and to reconnect it to the other main sources of Palladio's history, the design drawings, in which references to not yet identified fireplaces frames can sometimes be found.
On the other hand, the fireplaces show all the typical 3D-based "*measure and draw*" issues in AH: from acquisition (dimensions, formal features, surface properties), to reconstruction (semantics), to interpretation (building modalities, shape of frame sections). In two editions of the course, from the academic year 2021-2022 to the 2022-2023, 29 different fireplaces by Andrea Palladio, located in many of his villas, were considered as ideal case studies to be analyzed and replicated by the students, as these elements were useful in the understanding of the design principles followed by the great architect in the Renaissance.

4. TECHNOLOGICAL UNDERPINNING

In recent years, smartphone camera technology has made formidable improvements regarding sensors quality and software performance, still improving year after year, supported by flourishing of scientific research in the area. Recent smartphones, such as the Apple iPhone 14 and the Huawei Mate 50 Pro, reach levels of image resolution, sharpness, and color accuracy sometimes better than prosumer SLR cameras, enabling on-the-fly processing and procedures which were considered impossible to do until a few years ago. The current fast integrated 5G communication technology implemented in smartphone devices allows to transfer the recorded pixels easily and quickly to on-board or cloud-based servers for further processing and 3D reconstruction purposes (Nocerino et al., 2017; Apollonio et al., 2021). These favors on-the-fly online dissemination of 3D models, a totally new method. Furthermore, a smartphone is in the pocket of each of us. It is not an instrument limited to a small number of specialized users, such as laser scanners and high-end photogrammetric applications are, but an integrated low-cost, easy-to-use, and easily transportable sensor. Used in combination with simple mobile phone applications (*apps*), it can supply millions of users with a multipurpose low-cost 1D-2D-3D acquisition system, easily exploitable with just some taps, and a low a quick sharing of the data acquired. However, while issues like geometric distortion, lens shading (a type of vignetting) and chromatic aberration can largely be automatically fixed, two main problems today prevent users to get accurate results from photogrammetric purpose. The first depends on a construction constraint: the tiny image sensors in smartphone cameras cannot capture as much light as the bigger sensors of SLR cameras, and the high density of pixels lets the light influence the adjacent elements. The second issue consists in the limited number of experiments carried out on smartphones radiometry, whose consistency is a main requirement in architecture, AH and CH, despite the many experimental results presented in the field of geometry (Poiesi et al., 2017; Boboc et al., 2019; Tariq et al., 2021). Furthermore, the pervasively distribution of these integrated low-cost, easy-to-use, and easily transportable sensors is possible due to a set of 'black boxes', namely a complex ensemble of proprietary software and hardware solutions, implemented inside smartphones, not allowing a quick and certain verification of the typical parameters on which to ground the captured data. To solve these problems a new specific education in image processing and photogrammetric concepts, besides the well-established instruction, is needed. On the other hand, since smartphones can manage different tasks, they are an effective learning tool to understand the basic principles of digital photogrammetry.

5. THE STUDENTS' ACTIVITY

5.1 Preamble

The didactic initiative involved about thirty students attending two editions of the *Photogrammetry for Architecture* course. Students' primary goals were the production of 3D models of the Palladio's fireplaces, to support future multiple uses from documentation to visualization (batch renderings, Real-Time Renderings, AR and/or VR applications, multimedia, simulation applications (Figure 2), to technical drafting inferred by 3D models aiming to reconstruct the design technique of the architect (who, as known, often uses two-dimensional proportions) (Figure 3). The in-place activities were parallelly done with theoretical introduction of photogrammetric principles during classes (illustrated with examples and collaborative applications on real case studies: the façade of a beautiful palace by the architect Baldassarre Peruzzi and two bays of a porticoed building). Basic concepts such as image capture and processing, collinearity, camera models and calibration, bundle adjustment, structure from motion, dense stereo matching, and general shooting rules with a camera network for optimal photo-reconstruction in architecture were exposed.

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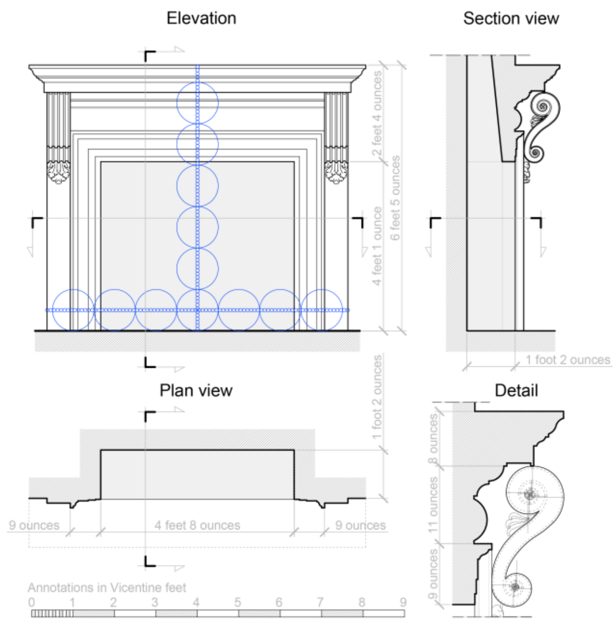

Figure 3. The extraction of 2D CAD drawings from 3D models (drafting by D. Festa, detailing by S. Amodio).

Once the smartphone-based photogrammetric workflow was introduced, students were asked to preliminary check the available specifications on their smartphones, such as sensors dimensions and resolution, to carefully plan their survey later and to calibrate the device using self-calibration techniques (Luhmann et al., 2016) against a common architectural element (a well-featured portal of the Palazzo Albergati by Peruzzi). All these operations were carried out and discussed collectively. After this preliminary empowerment, the learning activity referring to the Palladian fireplaces began. At first students had a half-day introduction to the features of Palladian buildings at the Palladio Museum in Vicenza, both from a design and construction point of view with dedicated lectures by the director and by the museum curator (both architecture historians). The day ended with a collaborative learning work consisting in a joint survey of the fireplace in the *Sala della Fortuna*, selected as exemplary case study. Exploiting this first case study, the evaluation of the camera capture distance to achieve the desired GSD with their smartphones was introduced and experimented. Secondly, different datasets with different GSD were captured to evaluate the best solution to achieve the final required resolution of the 3D model of the fireplace. Some 3D models were quickly produced for the assessment. This introduction was then followed by a second day at the Villas where fireplaces are located.

5.2 The workflow at the Villas

Once at the Villas, students were split into groups of two or three, even though they were rejoined for brainstorming sessions, information sharing, and group analysis. In fact, fireplaces to be surveyed were selected and assigned to groups of students according to different levels of complexity, generated by their size and position; the materials used to fabricate them; backlight shooting problems due to windows in the same wall of the fireplace without any possibility of obscuration; close windows; specular reflections generated by polished marbles; presence of obstructions (e.g., the Aura installation by Zaha Hadid at Villa Malcontenta, some scaffoldings at Villa Cornaro, etc.). With the aim to guarantee the expected outcomes in terms of 3D model production able to digitally replicate the fireplaces, their proportions, and their appearance, the first step of the student work was an analysis of the assigned manufact to correctly design the data capture phase (camera network, number and position of color targets, shots needed, lighting conditions, artefacts materials behavior, type of tripod or stepladder needed, etc.). Starting from a well-established workflow, they were demanded to customize it depending on features of the fireplace to be surveyed and its surrounding environment. They were also provided with some Calibrite ColorChecker Classic targets, for the color correction of the pictures. Students had to consider it at a proper distance and inclination, to find the solution ensuring the most faithful color reproduction avoiding glare, shadows, different capture conditions between the target and the artefact and to minimize the number of the target images used. Their final step was the measurement of main dimensions of the fireplace, to scale the final model once produced both using rulers and a Leica BLK360 laser scanner. These measures will allow, later at home, to reconstruct the proportion used by Palladio for their design according to the units adopted (the *Vicentine feet*).

5.3 The workflow in the lab

After checking that all the datasets were successfully collected, students had to crystallize their skills and knowledge from the *in-situ* activities with further operations in laboratory. To avoid the

Figure 4. 3D models of fireplaces produced by the students: Villa Cornaro (left side) and Villa Godi Malinverni (right side). 3D models by S. Amodio, L. Bonaparte, V. Bonesi, N. Costantini, E. Covato, V. Daga, B. Ferri, D. Festa, F. Gradone, J. Lubelczyk, M. Mazzetti, L. Pedrucci, K.Perolli, G. Savoldi, D. Tondelli, D. Toro, and F. Useri).

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learning of commands belonging to specific software, but to get the application principles instead, they followed two separate pipelines to author their 3D models. The automated workflow in Agisoft Metashape was compared to the combination of cameras alignment performed in Colmap and the dense 3D reconstruction workflow in n-frames SURE. Observing the results from the two pipelines starting from the same image dataset they learned from their errors. In this phase students also practiced on 3D meshes optimization, on how to prepare color corrected textures to be applied to the models, improving their skills on open-source software such as Meshlab and CloudCompare and our RAW converter and color corrector SHAFT (Gaiani, 2018). Finally, they discovered how to extract 2D vector views, sections and profiles from the 3D models and they imported it in a 2D CAD system, Autodesk AUTOCAD.

6. RESULTS AND CONCLUSIONS

In figure 4, some 3D models developed by students are presented. The image wraps up the three key points of this learning path: the use of scientific knowledge as the basis for the survey of Palladio's fireplaces, the concept of digital copy as a reality surrogate able to show emotions and knowledge, the relationship between a real artistic or architectural artifact and its digital replica. The presented didactic experience converges into a 'Guided Discovery Architecture' and a 'Collaborative' method fostering active thinking through a continuous cycle of experience and reflection, thus limiting moments of passive reception of diverse content and disciplines. This paper described how this approach, inferred by the different perspectives of the architecture historian, the surveyor, and the designer, was integrated into a single workflow in a joint project between institutions sharing the same interest for a common theme: the architecture of fireplaces by Andrea Palladio. Learning by doing, students consciously better understood the knowledge about the use of materials and the constructive solutions to well preserve and conserve the past, to design future interventions parallelly to the photogrammetry learning. They were guided, this way, to handle real-life problems that will likely happen in their future professional work and to develop teamwork and problem-solving skills to overcome criticalities.

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