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Developing Digital Skills for Architectural Heritage: A Didactic Approach to 3D Mapping and Phygital Storytelling

Eslam Nofal [1,2], Raffaella De Marco [3], Alina Elena Voinea [4], Amina Rejeb [1]

[1] Department of Architectural Engineering, University of Sharjah, 27272 Sharjah, United Arab Emirates - (enofal, u24105458)@sharjah.ac.ae
[2] Department of Architectural Engineering, Assiut University, 71516 Assiut, Egypt – eslam.nofal@aun.edu.eg
[3] Department of Civil Engineering and Architecture, University of Pavia, 27100 Pavia, Italy – raffaella.demarco@unipv.it
[4] Faculty of Architecture and Urban Planning, Technical University of Cluj Napoca, 400114 Cluj-Napoca, Romania – alina.voinea@arch.utcluj.ro

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Abstract
This paper explores the role of digital and phygital technologies in enhancing architectural heritage education through two didactic workshops conducted in Sharjah (UAE) and Cluj-Napoca (Romania). Aimed at bridging the gap between theoretical heritage studies and applied digital practice, the workshops engaged architecture students in 3D photogrammetry, modeling, VR/AR applications, and 3D printing. The study investigates how immersive and tactile tools -particularly phygital approaches that combine physical and digital experiences- support skill acquisition, spatial interpretation, and collaborative learning. Through a mixed-methods evaluation, including surveys and observational data, the research examines the influence of regional, educational, and cultural factors on learner engagement and tool preferences. Results reveal differing emphases: immersive visualization dominated in Sharjah, while hands-on documentation and model precision prevailed in Cluj-Napoca. The findings contribute to the development of context-sensitive pedagogical strategies for digital heritage, offering a comparative framework for integrating technological training with heritage awareness in architectural education.

1. Introduction

Digital technologies, such as photogrammetry, virtual and augmented reality (VR/AR), and 3D printing, are transforming the way students interact with architectural heritage. These tools enhance spatial cognition, enable immersive and multisensory experiences, and support novel forms of interpretation and engagement (Ott & Pozzi, 2011; Pervolarakis et al., 2023). However, despite their growing adoption in experimental or research-driven contexts, their structured integration into architectural heritage training remains relatively limited (Giliberto, 2021; Parrinello & De Marco, 2022).
Many architectural and design curricula continue to prioritize digital tools for parametric design, visualization, and fabrication, often at the expense of heritage documentation and analysis. As a result, students frequently lack hands-on experience with applying these tools to existing historical sites. When digital technologies are included, they are often detached from critical engagement with heritage values or from meaningful field-based application (Hess et al., 2017; Di Mascio et al., 2018).
To address this pedagogical gap, the current study evaluates two didactic workshops conducted at the University of Sharjah (UAE) and the Technical University of Cluj-Napoca (Romania). These workshops were designed to immerse architecture students in digital heritage workflows, ranging from 3D photogrammetry and modeling to immersive visualization (VR/AR) and phygital experience. Phygital, a hybrid term combining "physical" and "digital," refers here to the use of tangible outputs (e.g., 3D-printed models) in conjunction with digital interfaces to create multi-sensory, interactive learning environments (Nofal et al., 2017).

The study focuses on three core areas:

- The development of digital skills through applied training.
- The impact of phygital methods on learning experience.
- The influence of regional and institutional context on learner engagement and tool preferences.

Accordingly, the research is guided by the following questions:

- How do workshops contribute to building digital skills in heritage contexts?
- In what ways do phygital tools support learning and interpretation?
- Do educational and cultural backgrounds shape students' engagement with different tools?

By analyzing student feedback, task performance, and contextual variables across both workshops, this study offers comparative insights into how digital and phygital tools can enhance heritage education. It aims to contribute to the design of context-sensitive pedagogical models that link technological proficiency with heritage awareness and narrative engagement.

2. Literature Review

The integration of digital technologies (e.g., 3D modelling, photogrammetry, virtual and augmented reality (VR/AR), and 3D printing) is reshaping the ways students engage with architectural heritage. These tools enhance spatial understanding and foster student motivation through immersive and interactive experiences. As highlighted by Ott and Pozzi (2011) and Paolanti et al. (2021), VR and AR are particularly effective in developing spatial cognition and emotional engagement, enabling learners to explore architectural narratives beyond traditional classroom boundaries.
Building on these immersive strategies, phygital learning environments are gaining traction in heritage education. By combining digital interfaces with physical artefacts (e.g., 3D printed models), phygital approaches offer intuitive, multi-sensory learning experiences. Nofal et al. (2017) and Hallot et al. (2021) underline the pedagogical value of tangible interaction, showing that such hybrid environments support enhanced memory retention, collaborative learning, and situated understanding
Within this evolving pedagogical context, workshops have emerged as powerful tools for digital skill acquisition. Designed as hands-on, interdisciplinary learning experiences, they offer students the opportunity to engage directly with digital

documentation techniques, often using accessible equipment like smartphones and entry-level photogrammetry software. Studies by Di Mascio et al. (2018) and Tucci et al. (2018) show that these formats accelerate skill development and foster active learning through experimentation and iteration.

Despite these advances, the diffusion and effectiveness of digital heritage practices vary significantly across regions. Research by Münster et al. (2021) and Hess (2020) reveals that engagement with digital tools is influenced by background, institutional infrastructure, and prior exposure to technology. While European institutions tend to lead in integrating these tools within heritage curricula, the Middle East demonstrates growing interest through context-specific adaptations. However, there remains a notable lack of comparative studies systematically examining how regional, educational, and cultural differences shape digital literacy and tool preferences in heritage education.

To address these gaps and expand on current pedagogical practices, this study investigates two didactic workshops conducted in Sharjah and Cluj-Napoca. The workshops were designed to explore how digital and phygital tools, such as photogrammetry, 3D printing, and immersive technologies, can foster architectural heritage understanding, technical skill acquisition, and experiential learning. Their implementation offers a framework for evaluating both the learning outcomes and contextual variables that influence the integration of digital methods in heritage education.

3. Methodology

3.1 Workshop Design and Implementation

The purpose of the research was supported by the design of a specific workshop program dedicated to the transmission of practical skills related to digital datasets in the field of Architectural Heritage. The program was structured on hands-on tasks aimed at illustrating well-defined and practical digital skills to students, while introducing them to a novel educational action and to the broader scientific concept of Digital Heritage. Figure 1 shows examples of datasets and typologies explored during the workshops.

The workshop cycle comprised two events, hosted respectively at the University of Sharjah (United Arab Emirates, October 2023) and the Technical University of Cluj-Napoca (Romania, June 2024), both within undergraduate and graduate programs in Architecture. In both contexts, participants generally had limited or no prior exposure to digital documentation or Digital Heritage development.

Thus, the two institutional contexts were considered for shaping the specific didactic orientation of each workshop. In the UAE, the prevailing educational framework approached Cultural Heritage from a more theoretical perspective, emphasizing management and conservation planning. In contrast, the didactic background in Romania demonstrated pre-existing knowledge towards the practical elaboration of 3D data on historic architecture, often for application in design-oriented outcomes.

Considering these differences, the practical components were carefully adapted to suit each context. In the UAE, the activities were tailored to promote cognitive and narrative engagement with pre-prepared digital datasets. These datasets, derived from earlier research campaigns, featured historic architecture in the broader Arab region, though not specifically from the UAE. The workshop included case-study lectures to enhance theoretical understanding and illustrate potential applications.

In Romania, the pedagogical approach placed greater emphasis on student-led engagement. A site survey campaign was integrated into the workshop, allowing participants to collect their data through guided visits, on-site photography, and video documentation. This strategy yielded a more comprehensive digital corpus, enabling the exploration of architectural elements alongside decorative and historical furnishings.

As a result, the two workshops supported the design of two distinct instructional formats for the didactic structure:

- a *Technical-Illustrative* (TI) format in the UAE, aimed at raising awareness of digital tools and fostering understanding through curated content and narrative-based exploration with Digital Heritage.
- a *Practical-Replicative* (PR) format in Romania, emphasizing the generative approach to Digital Heritage, including data acquisition, processing, and personalized content development.

The following subsections describe the main categories of tasks proposed in the workshops and highlight the outcomes observed across the two instructional formats.

3.1.1 3D Photogrammetry: 3D photogrammetry concepts were delivered theoretically in the TI model (UAE) and through combined theoretical and practical sessions in the PR model (Romania). In the UAE, students were introduced to the fundamentals of projection geometry underpinning photogrammetric methods, with the presentation of international case studies to exemplify workflows, data typologies, and common challenges in heritage documentation. In Romania, greater focus was placed on data acquisition strategies and technical workflows. Students learned about photographic settings, acquisition trajectories, and data quality parameters. They conducted several hands-on exercises, including:

- Configuring photographic parameters on personal smartphone devices for 3D photogrammetry.
- Lab-based data capture, focusing on objects in the room or human figures (participants).
- On-site documentation of architectural components from the sites visited, such as bas-reliefs, inscriptions, liturgical furniture, and decorative features.

3D Modelling: No practical modelling sessions were conducted during the TI workshop. Instead, the emphasis was placed on understanding the interpretive potential of digital data and its role in heritage studies, proposing tasks of fruition and analysis of the datasets.

In contrast, the PR model enabled students to process their captured datasets using modelling platforms. They worked from 2D images to generate 3D datasets and data typologies, including photo alignment, point clouds, mesh models, and textured outputs (Figure 1). Students were also introduced to quality optimization tools such as mesh decimation, refinement, and smoothing, resulting in usable 3D datasets employed in later workshop phases. *Agisoft Metashape* was used as the primary software for these didactic tasks.

3.1.2 VR/AR Exploration: VR/AR implementation of datasets was conducted in both formats. Proposed activities covered the setup of immersive environments hosting heritage datasets, based on the *SketchFab* platform, and including:

- Scene composition (environmental settings, lighting, materials, background, effects).
- Navigation configuration (world scale, floor level, user orientation in the virtual asset).
- Content enrichment through interactive annotations (also applying markdown syntax for textual, visual, and audiovisual integration).

These activities aimed to equip students with the skills needed to construct narrative-rich, interactive heritage environments, reinforcing their understanding of both spatial and storytelling dimensions of the architectural sites.

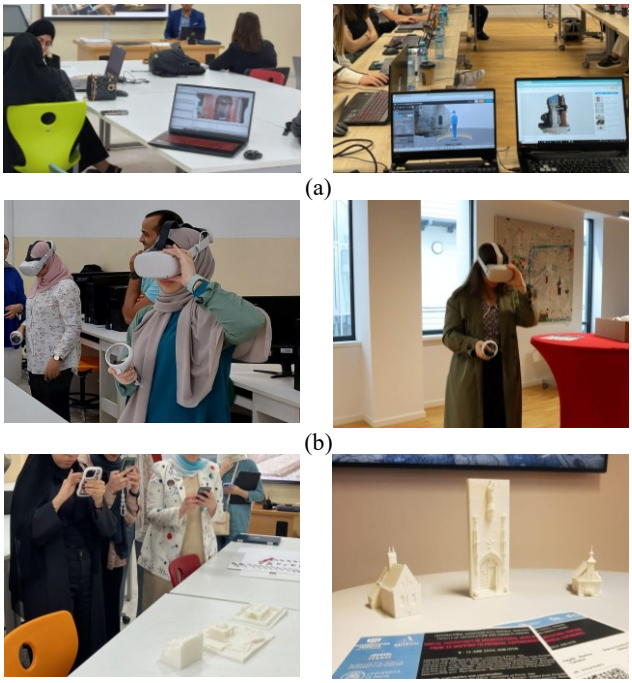
(a) (b)

Figure 1. Examples of architectural heritage datasets used in the two workshops: (a) multi-scale documentation and 3D reconstruction of a historic Maqam (shrine) site from the Sharjah workshop (UAE); (b) photogrammetric models of churches and interior architectural elements from the Cluj-Napoca workshop (Romania).

3.1.3 Phygital Exploration: The 3D prototyping of datasets related to architectural sites was developed in both workshops, in close collaboration with university laboratories equipped for digital fabrication. These physical outputs (i.e. produced through 3D printing) formed the foundation of structured phygital learning experiences, where students could actively engage in both tangible interaction and virtual navigation of the corresponding digital models. This hybrid approach enabled students to bridge digital processes with real-world materiality, reinforcing spatial and perceptual awareness. Two main modes of interaction were employed (as shown in Figure 2):

- *AR/VR navigation via personal smartphones*, allowing students to explore digital models directly through touchscreen input. Access to these web-hosted environments was made user-friendly through QR codes placed alongside the physical prototypes, encouraging fluid transitions between physical and digital modalities.
- *Immersive VR navigation using Oculus headsets*, which enabled students to interact with architectural models in immersive virtual spaces, using joystick controllers for spatial movement, orientation, and object inspection.

During the AR sessions, students were guided to compare the virtual representations on their screens with the 3D-printed prototypes in the learning space. This juxtaposition encouraged critical reflection on spatial accuracy, dimensional coherence, and the interpretive potential of digital documentation when translated into physical form.



(a) (b) (c)

Figure 2. Workshop workflow (left side: University of Sharjah, and right side: Technical University of Cluj-Napoca); (a) Activities of 3D mapping and photogrammetry, (b) VR/AR experiences, and (c) phygital output and experiencing the 3D printed models.

The phygital setup proved particularly effective in deepening engagement, as it combined cognitive, sensory, and interactive dimensions of learning. It also facilitated peer discussion and collaborative critique, with students exchanging observations about modeling precision, representational choices, and the effectiveness of phygital storytelling for architectural heritage communication. Overall, the integration of physical and digital interaction helped to consolidate technical skills while promoting a more holistic and embodied understanding of architectural data.

3.2 Evaluation Approach

A mixed-methods evaluation was employed to assess both the educational impact and usability of the workshops conducted in Sharjah and Cluj-Napoca. The survey was tailored to each context: in Sharjah, 10 participants responded, providing their impressions and opinions; in Cluj-Napoca, 24 Romanian participants completed the survey and shared their feedback. To ensure accessibility and efficient data collection, the questionnaires were administered via Google Forms. This format facilitated both quantitative and qualitative analysis through Likert-scale items, multiple-choice questions, ranking preferences, and open-ended responses.

Each questionnaire contained approximately 46–47 questions and was structured into five analytical dimensions. The first dimension gathered general information such as participants’ age, educational background, and cultural context, enabling comparative analysis across demographics. The second dimension assessed prior exposure to digital tools—including photogrammetry, VR, and AR—to establish a baseline of digital familiarity. The third and most extensive section evaluated participants’ workshop experience, focusing on engagement, motivation, ease of use, and perceived creativity. Here,

participants reflected on their interaction with specific tools and activities, helping to assess usability and educational value.
The fourth dimension explored how participants perceived and interpreted architectural features through virtual and phygital tools, offering insights into their ability to recognize materials, textures, and spatial configurations. Finally, the fifth section collected open-ended feedback on overall workshop impressions, perceived learning outcomes, and suggestions for future iterations.
Quantitative data were analyzed using descriptive statistics and ranking analysis, while qualitative feedback was examined through thematic analysis to identify recurring insights. The evaluation also included the behavior observations during both workshops and a comparative component between them, allowing reflection on how cultural and institutional differences shaped participants' engagement, preferences, and skill acquisition.

4. Results and Discussion

4.1 Digital Skills Development

According to the answers obtained from the surveys designed for the two groups of participants, from UAE and Romania, the participants valued the focus of the workshop on acquiring and developing digital skills. While the students were familiar with the aforementioned technologies, the concept of phygital was a new one. The workshop was designed with participatory premises. Students were involved in data acquisition with their own camera devices and with the drones while on site visits. Moreover, at the stage of data processing participants learned new tools of photogrammetry and were guided in digital reconstitution. Finally, students were guided in publishing and witnessed the results with 3D printing and visualized the digital results online using AR and VR.
Workshops supported rapid skill acquisition, particularly among early-year students, who were more inclined to learning new digital skills and data processing, while students from final years valued more building of knowledge and implications of skills in enhancing knowledge and understanding. Overall, the learning process in the workshop had an organic process since the workshop was designed both with knowledge transmission in lectures from invited lectures and trainers, as well as with training sessions and guided applications.
Engaged teaching and student curiosity contributed to effective learning outcomes. Bridging between digital skills and architectural heritage has enabled students to be more receptive to Architectural Heritage concept for those oriented towards digital skills, and the ones interested in AH were more motivated to develop digital skills. This way, the learning experience expanded for all the participants broadening the curiosity towards new fields of the heritage domain, either more technical or historically.
First- and second-year students showed more focus on technical skill-building, while advanced students sought deeper integration of skills with architectural interpretation. The workshop provided tools in data acquisition and digital reconstitution.
Some participants suggested earlier introduction to tools before field visits would enhance accuracy and confidence. Architecture students reported different previous experience in Romania and UAE. If all Romanian students experienced digital technologies before the workshop, participants from UAE didn't have previous experience with AR. Romanian participants had less experience in *Sketchfab*, while VR and point cloud database were the on the second place. 3D printing was noted as the most familiar skill.
Hence, after the first workshop in the UAE, students noted several technical challenges, particularly with the installation and use of photogrammetry software. Difficulties also emerged during the publishing phase, where participants encountered barriers in rendering and sharing their outputs. These challenges highlighted a need for more guided technical support and preparatory instruction. Despite these issues, participants responded positively to the opportunity to engage with new tools, especially 3D printing and VR, which many cited as enjoyable and educational experiences in relation to architectural heritage.
The second workshop in Romania benefitted from the lessons learned in the UAE, showing improved structure and support. Romanian participants appreciated the chance to develop skills in new software programs, particularly photogrammetry, and expressed interest in continuing their learning beyond the workshop. However, many students suggested that earlier training in photogrammetry, before the site visit, would have improved their confidence and data accuracy. Participants were generally motivated to deepen their knowledge, noting a desire for more time to interact with the tools and for expanded applications. While photogrammetry was the most novel and engaging for most students, opinions on time allocation varied depending on prior experience and comfort with digital tools.
Students expressed interest in future follow-up projects, indicating strong engagement and perceived relevance of the training. While in UAE participants predominantly reported experiencing new digital tools, gaining new information related to AH and being engaged in interesting/ exciting time, participants in Romania also noted in majority practicing new learning environment and being involved in interactive collaboration with peers. Although the workshop involved interactive and collaboration with peers, students in the second workshop underlined the desire for a more participatory process and openness of the organization facets of the workshop itself.
Overall, participants manifested the will to extend the workshop timewise and within other fields of study. Important aspects grasped from the survey are the desire for the learning process to last longer and for the interaction with each of the digital tools including technical information and practical interaction with the tools.
The initial workshops in the UAE and Romania demonstrate the potential for expanding the training model to include both (i) *pre-training,* in digital tools and the identification and documentation of architectural heritage; and (ii) *post-training*, focusing on the analysis, interpretation, and application of digital data in the context of architectural heritage and Digital Architectural Heritage (DAH) practices.

Quantitative data from surveys can illustrate:

- Self-reported skills growth

UAE participants with 3D printing and VR previous experience mentioned VR, AR and 3D printing as features describing the experience within the workshop. Students evaluated positively all the experience with the digital tools in experiencing AH, both the space and information about AH. Seventy percent of the participants chose VR as primary experience to educate about architectural knowledge, while AR was the second tool reported.
In the case of Romanian participants with preponderantly 3D printing skills, during the workshop they gained experience with all the tools, preponderantly with photogrammetry, the second preferred tools being virtual reality. Fifty percent of the students chose VR as primary experience in education about Architectural knowledge, while for the second workshop the opinions about the experience were evenly distributed, except for the least experienced tool during the workshop was 3D

printing since it was already known before it did not stimulate interest and curiosity.

- Preferred tools

All participants were familiar with 3D printing tools, UAE students also with VR. After the workshop, participants unanimously reported achieving experience with new digital tools. The most preferred tools by participants were VR and AR. However, all tools contributed to the educational experience in architectural knowledge.

- Ease of use and motivation levels

The use of Photogrammetry, AR and VR tools gave students digital options in experiencing AH, both external and internal spaces. Also, digital tools enriched participants with tools of understanding and acquiring information reinforcing their abilities to represent AH.

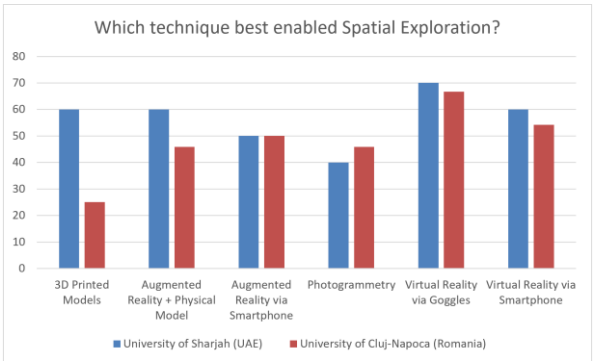
4.2 Phygital Storytelling and Engagement

The workshops adopted a hybrid digital-physical approach that merged advanced digital documentation techniques (i.e., photogrammetry and immersive VR/AR environments) with tangible outputs, most notably 3D printed models, to foster a comprehensive and engaging phygital storytelling environment. This integrative method facilitated technical skill development while supporting deeper conceptual understanding by linking digital processes with physical outcomes. Grounded in experiential learning theories, particularly Kolb's learning cycle (1984), the workshops encouraged students to engage in iterative cycles of observation, active experimentation, and reflective practice. By interacting with both virtual simulations and physical models, participants could contextualize and internalize architectural knowledge in a multi-sensory manner.

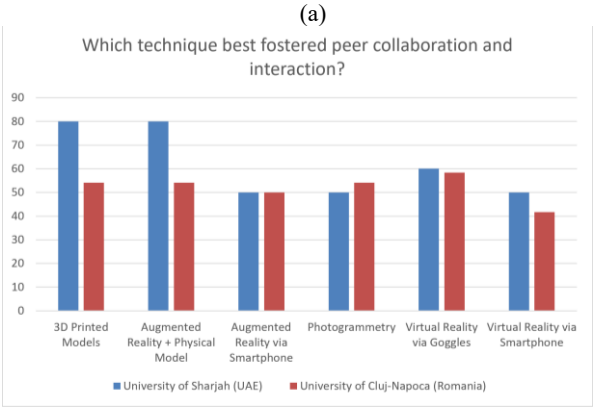
The 3D printing phase was especially impactful, providing a tangible manifestation of the digital workflow—from data acquisition via photogrammetry to the final physical object. In both workshops, students exported their processed models and worked closely with digital fabrication labs to produce accurate replicas, enabling them to critically evaluate spatial geometry, scale, and detail fidelity. This tactile engagement enhanced their architectural perception and supported the translation of abstract digital data into physical form. It also introduced them to the full spectrum of a digitization-to-fabrication pipeline, which is increasingly relevant to contemporary heritage and design practices.

Quantitative feedback reinforced these findings. While Virtual Reality (VR) was most frequently selected as the primary tool for spatial exploration—by 70% of participants in Sharjah and 48% in Cluj-Napoca—3D printed models emerged as the top choice for fostering collaboration and peer interaction, particularly among Romanian students (32%) (Figure 3). Participants emphasized that the physicality of 3D printed artifacts deepened their connection to the subject matter, making the learning process more engaging and meaningful. Additionally, the juxtaposition of immersive and tangible experiences was frequently cited as a strength of the workshop: VR facilitated dynamic exploration of space and form, while physical models grounded discussions in shared, real-world references that enhanced team-based interpretation.

The integration of digital and physical tools proved an effective pedagogical strategy, enhancing both cognitive and social aspects of heritage education. By linking theory with hands-on practice, it fostered deeper understanding, encouraged collaboration, and maintained strong student engagement throughout the learning process. The results further suggest that phygital strategies could be widely applicable in architectural and heritage education, offering a replicable model for interdisciplinary, project-based learning.



(a)



(b)

Figure 3: Comparative Analysis of workshop outcomes between University of Sharjah and Technical University of Cluj Napoca; (a) the techniques that best enabled spatial exploration of the architectural heritage, and (b) the techniques that best fostered collaboration and interaction during the learning process.

4.3 Regional Comparison: Digital Visualization vs. Practical Applications

While both workshops achieved their educational objectives, participant feedback revealed nuanced regional differences shaped by educational background, digital familiarity, and workshop design. These contrasts highlight distinct learner priorities and levels of technical engagement in Sharjah and Cluj-Napoca.

In Sharjah, most participants encountered digital heritage tools for the first time. Their feedback reflected strong enthusiasm for immersive digital environments, with Virtual Reality (VR) emerging as the most appreciated feature—selected as the primary educational experience by 70% of respondents (see Figure 4). Augmented Reality (AR) followed as a secondary preference, reinforcing the excitement around exploring unfamiliar technologies. Participants emphasized the novelty and engagement of these tools, describing VR as "*a creative way of learning architectural heritage*" and expressing satisfaction in "*showing the models after finishing*." In contrast, physical models and 3D printing received less emphasis, with fewer participants identifying them as meaningful components of the learning process. This suggests that in introductory contexts, immersive visualization tends to overshadow tangible interaction.

In Cluj-Napoca, participants arrived with stronger prior exposure to digital tools such as photogrammetry and 3D modeling. Their feedback revealed a more balanced engagement across the workshop's digital components, as illustrated in Figure 4. While VR remained the top-ranked experience (48%), both AR and 3D printed models were each selected by 24% of participants as their primary tools.

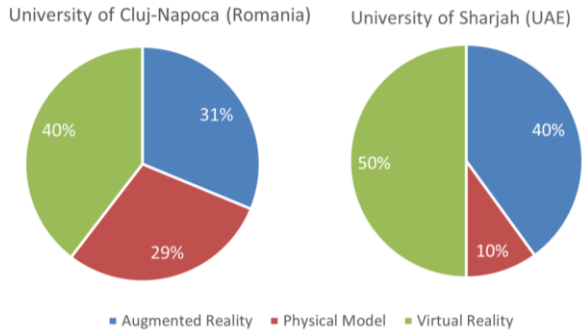


Figure 4: Percentages of students selecting the technique they found most educational.

Photogrammetry was particularly well received for its technical applicability, with students highlighting the "*learning process of point clouding*" and noting that "*photogrammetry allows us to make our lives easier as architects*." 3D printing, too, gained recognition for bridging digital modeling with physical outcomes—32% of participants cited it as a key secondary experience. These insights indicate a stronger emphasis on practical workflows and technical depth among Romanian participants.

Differences also emerged regarding the integration of heritage narratives and historical context. In Sharjah, several participants expressed a desire for more interpretive content, requesting background on the significance of the heritage sites. Comments such as *"Was expecting more historic background information on the architectural elements"* and *"The significance of the place! Why it is important!"* highlighted a gap in contextual framing. In contrast, the Cluj-Napoca workshop included historical presentations and on-site lectures, which were well received. Participants described these sessions as *"very engaging and fun,"* noting that the added context *"allowed us to better understand what the end phygital experience should convey."* This comparison underscores the importance of embedding narrative and historical interpretation into digital heritage training to enhance educational depth and participant engagement.

Taken together, these regional variations illustrate how students' engagement with digital heritage education is shaped by their academic preparation, technical confidence, and expectations of content depth. While Sharjah participants gravitated toward immersive visualization and exploratory learning, Cluj-Napoca attendees sought deeper technical engagement, interpretive framing, and tangible outcomes. These distinctions demonstrate the need to adapt digital heritage training to local contexts, learner profiles, and prior exposure. They also underscore the importance of flexible instructional design that can respond to differing pedagogical needs and learning trajectories.

These regional differences reflect the impact of the two distinct instructional formats adopted. The Technical-Illustrative (TI) format in Sharjah prioritized conceptual understanding and immersive exploration through curated content, which resonated with students encountering digital tools for the first time. Meanwhile, the Practical-Replicative (PR) format in Cluj-Napoca emphasized hands-on engagement and technical workflow replication, aligning with participants' prior familiarity with digital methods. This contrast highlights the importance of aligning workshop structure with students' educational backgrounds to maximize learning outcomes in digital heritage training and foster deeper disciplinary integration.

5. Conclusion and Future Work

This study highlights the effectiveness of didactic workshops as a scalable and context-sensitive model for developing digital competencies in architectural heritage education. By combining immersive technologies (e.g., VR/AR), 3D mapping, and tangible outputs like 3D printed models, the workshops offered a comprehensive phygital learning experience. Participants engaged in iterative processes of data acquisition, interpretation, and physical reproduction, reinforcing both cognitive and experiential learning outcomes. The integration of phygital storytelling not only enriched heritage perception but also fostered meaningful engagement with architectural narratives through multi-sensory and collaborative formats.

The comparative implementation of the two instructional formats—Technical-Illustrative (TI) in the UAE and Practical-Replicative (PR) in Romania—demonstrated how regional academic infrastructures, prior exposure to digital tools, and cultural learning expectations can shape workshop design and impact. While Sharjah students responded more enthusiastically to immersive visualizations, Cluj-Napoca participants emphasized hands-on documentation and model accuracy. These findings underscore the need to customize digital heritage education according to specific learner profiles and institutional contexts.

Figures 3 and 4 support the conclusion that combining digital and physical methods enhances both technical skill acquisition and social learning. Moreover, the success of these workshops points to the value of structured, accessible workflows for digital heritage practices that can be replicated across educational settings.

Looking ahead, future research should examine the long-term influence of such workshops on students' professional pathways in architecture and heritage conservation. Longitudinal studies could evaluate how early exposure to phygital tools affects participants' engagement with digital heritage in academic, research, and industry contexts. Additionally, there is potential to scale this pedagogical model across disciplines—such as urban planning, museum studies, or archaeology—where experiential and data-driven heritage learning can be equally transformative. Integrating pre-training modules, follow-up project-based learning, and cross-institutional collaborations will further strengthen the impact and sustainability of this approach.

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