The Use of Photogrammetry in Historic Preservation Curriculum: A Comparative Case Study

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Abstract

Computer graphic techniques have emerged as a key player in digital heritage preservation and its dissemination. Photogrammetry allows for high-fidelity captures and virtual reconstructions of the built environment that can be further ported into virtual reality (VR) and augmented reality (AR) experiences. This paper provides a comparative analysis of historic details and building documentation methods in heritage preservation in the context of architectural education. Specifically, it compares two educational case studies conducted in 10-year intervals documenting the same set of historic artifacts with corresponding state-of-the-art digital technologies. The methodology for this paper is a qualitative comparative analysis of two surveying projects that utilized distinct emerging digital technology while sharing the same study subjects and similar tool-driven curricular framework. The research also incorporates a student survey, offering perspectives on teaching strategies and outcomes within this dynamic educational context. The outcomes demonstrate that the technological (tool-driven) shift impacts the way students interact with the investigated artifacts and the changing role of the interpretative versus analytical skills needed to delineate the work. It also changes what are considered primary and secondary knowledge sources.

CCS Concepts

• ***Applied computing*** → ***Arts and humanities;*** *Computer-aided design;* ***Education;***

1. Introduction

Emerging imaging technologies create opportunities for new ways of building documentation and surveying by capturing high-fidelity spatial data that include textural and chromatic information in addition to 2D and 3D geometries. These photogrammetric models are created by extracting detailed 3D information about an object or environment from a series of overlapping photographs captured from various angles. The use of common features found in these images, such as points, edges, and textures, enables the calculation of the spatial relationships between these features. These relationships are then used to reconstruct the 3D geometry [Sch05] [Lin09].

This paper discusses curricular strategies in the area of architectural heritage that integrate emerging digital imaging techniques and reflects on the conceptual shift in the ways historic preservation is documented and presented. It shows how building preservation curricula can reflect the continued evolution of digital tools and conceptual frameworks associated with them. Specifically, the paper focuses on two survey studies conducted at the historical Old Cemetery in Lodz, Poland, in 10-year intervals, with both studies utilizing distinct state-of-the-art digital tools.

2. Background

Drawing documentation plays a critical role in architectural design and historic preservation by providing a visual and accurate record of design intent and/or characteristics of existing conditions [MP10] [GAM*18]. It supports creative thinking and decision-making as well as guides conservation efforts by ensuring that future preservation projects are carried out with respect for the historical integrity of the site. Drawing surveys can also serve the role of 'time capsules' documenting a particular condition of the structure at a given moment and often are seen as a form of more or less subjective interpretation of an object.

2.1. Building surveying

Analog methods of measuring and depicting buildings have been established since at least the early 15th century. Filippo Brunelleschi and Donato di Niccolò di Betto Bardi, aka Donatello [Coo19] surveyed ancient ruins, to study features and elements of Roman architecture [BBGG23] that served as analytical and synthetic knowledge-capturing repositories later adopted by early Renaissance artists. The importance of this approach was recognized by Giorgio Vasari defining the documentation process as measure (*misurare*) and draw (*disegnare*). Since then, the phrase

DOI: 10.2312/eged.20241004

'measure and draw' has been widely used as a description of processes crucial for education and research not only in architecture. Another concept proposed by Vasari was the dialectic relationship (dichotomy) between imitation (*imitazione*) and invention (*invenzione*) [Vas23]. In this approach, imitation becomes a 'mechanical' reproduction of artwork that facilitates learning and guides artists in the development of higher levels of visual mastery [Che17], while the invention originates ideas themselves. Thus, imitation subscribes to the logic and intentions behind the 'measure and draw' methodology and is often seen as a prerequisite to innovative design through the process of continuous abstracting and iteration. Methods described by Vasari were widely used without significant modification until more recent times. This tradition persists where architecture continues to be learned from past precedents. In the early 1990s, students would study past precedents by creating 3D computational models of renowned architectural works (Di Mascio et al., 2016), developing new forms of representation [NS14], and exploring spatial qualities of buildings through lighting, materiality, and narratives [DM17] [DM20]. However, analog methods remained an essential part of architectural education and practice.

2.2. Survey methods

Computer-aided Aided Design (CAD) methods known since the 1960s ushered in a gradual change in the surveying process. CAD drawings have the advantage of replicability and ease of revisions. However, the introduction of CAD in this domain brought also pushback from traditionalists–opinions were initially divided among architects and conservators. Many argued that CAD drawings did not capture the essence of the building and appeared too sanitized, and therefore inappropriate for such application [Ash95]. The subsequent graphic processing was conducted using computers, which resulted in a 'hybrid' traditional and innovative tool model. The early 2000s demonstrated that architecture and conservation practices benefited from the use of computer technology [See01] [KWW03], which continuously evolved over the following decade with CAD software being slowly replaced by new platforms by providing a deeper insight into both the present geometrical configuration and the constructive phases allowing other analyses [Man18].

While photogrammetric applications in heritage preservation are not new, in the past multiple studies have demonstrated their applicability and performance [RC19], the contribution of this study is to illuminate the accessibility of this technology, broader user base, and extensive range of applications. The accessibility also means low cost, which is vitally important for the entry of technology into widespread use, including academia [NTC15] [LML16].

Robert Warden [War09] pointed out that with digital technologies the surveying process has changed dramatically, however, the principal aims of built heritage recording remain the same: accurate documentation of objects and obtaining maximum information necessary for heritage conservation and promotion. This points to new opportunities for reconceptualization of how digital heritage and historic preservation are communicated and disseminated [ON16].

3. Project Setup and Methods

Two historic preservation surveys of tombstones at the historical Old Cemetery in Lodz, Poland, serve as case studies Each study surveyed the same group of monuments using technologies that were relevant at the time they were conducted: 2013 and 2023. Both surveys were conducted with the students in the professional architectural programs.

The first study, aka 'analog-to-digital', was conducted in July 2013 as part of a two-week summer internship in historic preservation, a mandatory curricular component in the professional architectural program. Students surveyed 12 tombstones. The tombstones were manufactured by the leading stonemason's workshop of the Urbanowski Brothers [BS13] in the late 19th and turn of the 20th centuries featuring forms typical of that period with a predominance of classical, romantic (naturalistic), and Art Nouveau styles (Figure 1). The initial documentation involved on-site hand-made measurements and free-hand sketches in addition to photographic documentation with the leveling rod for recording the scale of the individual components. The on-site surveying required a high level of precision and attention to detail due to sophisticated geometries and intricate ornaments. Scaled photographs (with the help of the leveling rods) were particularly helpful as CAD-based work was done off-site. Students utilized CAD tools supported by intermediate hand measuring, photography, and sketching. The final delivery included 2D computer-generated sectional drawings, elevations, and projections. The materials developed during the internship formed the basis for the creation of virtual models during the following semester.

Figure 1: *The scenery of the Old Cemetery with the turn of the twentieth-century details and stylistics.*

The second study (May 2023) used photography and photogrammetry software for data collection and 3D modeling. The project started with an introduction to photogrammetry and the conceptual frameworks of digital heritage and digital media arts focusing on (1) maintaining data integrity, (2) a proper environmental condition selection (lighting), (3) strategies for photo captures and 3D model creation, (4) 3D model and texture editing, (5) photogrammetric model optimization, and (6) visualization strategies. The study utilized a cross-platform (Android and iOS) app called KIRI Engine with each 3D capture using between 80-200 photographs. Once the 3D models were captured, they were exported as .obj files with associated textures (.jpg) and material mapping (.mat) files. These source models were then optimized and retopologized depending on the visualization platform. Mobile and game-based experiences require highly optimized and low polygonal geometries while being more forgiving to larger texture maps. Adobe Substance Painter was occasionally used to tweak texture maps and remove visual artifacts. Retopologizing was performed using the Blender software, which allowed the creation of various levels of detail (number of faces) models while preserving the original texture mapping alignments. The outcomes included 3D fully- textured models presented within WebGL (SketchFab) interfaces, rendered images, and narration- and time-based animations (Sketchup, 3DStudioMax) as well as Unity3D- and Prezi-based interactive presentations (Figure 2).

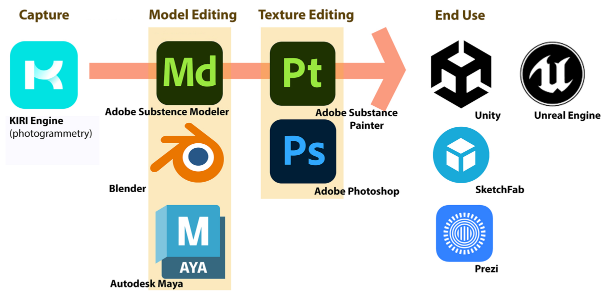

Figure 2: *The production pipeline utilizes the KIRI Engine for photogrammetry capture, Blender software for 3D geometry editing and optimization, Adobe Substance Painter for texture touch-ups, and Unity/Unreal game engines for experience delivery. Sketchfab was used as a model repository and sharing platform, whereas Prezi enabled interactive content creation for web-based presentations.*

4. Results

Study One relied on the individual subject observation, sketching of the primary compositional and spatial components with hand-based measurements. The manual survey with photographic documentation provided a base for 2D line drawings, which were later developed into spatial digital models. Study Two utilized a photographic process for capturing spatial geometry and textural maps. It operated exclusively within the digital pipeline for model correction, optimization, and visualization.

4.1. Study One (2013)

In the first phase of this project, 27 students worked in groups of three and four (eight teams) producing 12 tombstone documentations. The process employed hybrid methods including tape measures, hand sketches, and photography. The on-site measurements were converted into CAD drawings in addition to hand drawings that artistically captured tombstones (Figure 3).

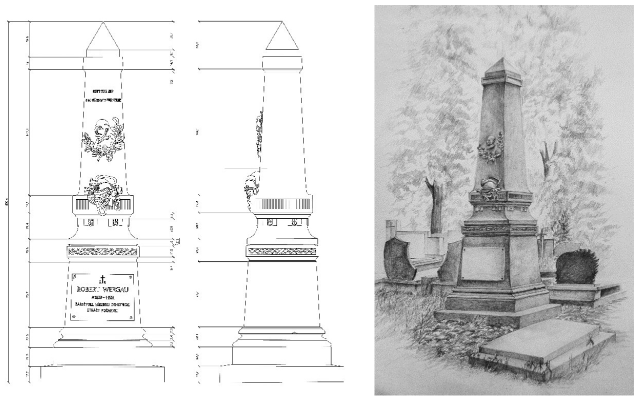

Figure 3: *Measured drawings of tombstones made with the use of CAD software (left panel) versus freehand drawings with artistic representations of surveyed tombstones (right panel) balance quantitative with interpretative documentation; archives of the Department of History of Architecture, Heritage Conservation, and Urban Regeneration TUL, 2013.*

In the second phase students created 3D digital models presented as hidden-line wireframes and realistic representations (Figure 4). These deliverables emphasized the geometric qualities (lines, points, shapes, and forms) over more evocative textural characteristics, such as materiality or form appearance revealed by lighting. Some of the students acquired actual textures while others used textures from software libraries that matched the original intent. In both cases, these were tileable textures extrapolating parts of the original into an overall representation.

Figure 4: *3D wireframe model of the monument (left panel), realistic rendering with the use of custom textures (right panel), archive of the Department of History of Architecture, Heritage Conservation and Urban Regeneration TUL, 2013.*

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The objective of both courses was to provide students with the required skills to document existing structures (phase 1) and create precise digital representations of architecture (phase 2), thus connecting with Vasari's concept of *imitazione*. Nonetheless, the task of producing sketches allowed students to express their creativity and interpret objects in artistic manner. During the creation of virtual models, students could also aim to generate visually appealing renderings of tombstones to evoke the ambiance of the cemetery site.

4.2. Study Two (2023)

25 students worked in groups of two and three (12 teams) producing 12 tombstone documentations. Each team developed multiple captures for assigned monuments considering various lighting conditions to identify optimal settings. Due to the automated nature of photograph-to-model creation, scanning several tombstones took only a couple of hours (3-4 hours) for each team. Similarly, preliminary processing, cropping, and uploading to the model share platform (SketchFab) took around an hour. Captured photogrammetric models were relatively lightweight with the face count ranging from 24K to 320K. Geometry editing and optimization, and presentations–did not involve reiterative processes common in design disciplines, which reduced reflection on the visualization.

Figure 5 demonstrates the range, scales, and types of tombstones used for scanning. Depending on the level of detail and form sophistication some of the scans required between 100-200 photographs. Since the scanning was conducted with hand-held devices, the preference was made for smaller structures. The photogrammetry process was particularly effective with tombstones with soft and dynamic shapes (Figure 6) as compared to traditional methods and those used in Study One (analog-to-digital).

Figure 5: *Examples of tombstones scanned as part of Study Two: Pladek's monument (Paulina Augustyniak and Karolina Krawczyk) (left panel) and Orlinski's monument (Agnieszka Jędruszek and Łukasz Polewczyk) (right panel). Both monuments represent types of free-form and highly detailed geometries that benefit from photogrammetric technology.*

An important part of this exercise was the documentation delivery, structuring user interactions that reinforced learning with various levels of detail and storytelling. Students were asked to reconsider conventional representational ways of historical preservation of information as a visual narrative that encourages question-asking and new interpretations. This part of the coursework was built upon a reflective (synthetic) layer idea in Bloom's taxonomy [Blo76] [Kra02] as well as Mayer's and Mitterecker's [MM17] postulate of optimal and effective simplicity without compromising 'important information.' Three main strategies that emerged from this study included:
(1) placement of the scanned architectural details (elements) within an overall hidden-line wireframe of the building or object. While the photogrammetric scans provided a desirable level of detail and materiality, the conceptual massing model showed the spatial arrangement, relationships, and comparative scale between objects and the whole (Figure 7). Visually, this approach helped to guide a viewer's eye and put an emphasis on selected components (Figure 8).
(2) Interactive, Prezi and WebGL-based presentations that allowed users to control their own experience. Presentations were structured as a set of nested geometries (akin to the matryoshka nested doll concept) starting with the overall view of the artifact and progressively, through the mouse clicks, unpacking various scales, elements, and details (Figure 9). This allowed for limiting the size and complexity of individual geometric models, thus enhancing visualization quality and reducing loading time.
(3) Development of the Unity3D-based interactive game environment that served as a spatial collage of individual tombstones. The presentation centered on isolating monuments and collaging them into a unique spatial composition that supported particular storytelling (Figure 10). Conceptually, it shared selected features from the presentation styles discussed above: (a) interactivity and user choice in content interactions and (b) establishing interrelationships between various objects. However, unlike in type (1) above, the relationships were not representative of actual buildings or structures, but rather a compositional juxtaposition akin to conventional 19th-century analytique drawing projected into 3D space.

5. Discussion

One of the shared goals for both courses was to develop a teaching approach for architectural education exploring 3D modeling and photogrammetry as a digital tool for historic preservation documentation including analytical and interpretative layers identified in Bloom's taxonomy [Blo76] [Kra02]. Student explorations were intended to provide a counterpoint to traditional ways of surveying, documenting, and visualizing historical heritage: to understand new opportunities afforded by emerging digital tools. These opportunities refer to education and curriculum development as well as ways to delineate visual information that enable new forms of historic artifact investigations and knowledge development.

5.1. Reflective Learning

The question of active learning in the context of digital tools emerges. The computational tools come with a certain degree of

Figure 6: *The closeup of the Orlinski's tombstone shows the level of detail and textures (left), the shaded model shows the quality of the surfaces (center), and the wireframe model shows the density of triangular mesh (right) (Agnieszka Jędruszek and Łukasz Polewczyk, 2023).*

Figure 7: *2D collage of 3D scanned monument superimposed over 2D drawing showing the overall organization of the wall assembly (Paulina Augustyniak and Karolina Krawczyk, 2023).*

Figure 8: *Spatial collage of 3D scanned monument superimposed over 2D drawing showing the overall organization of the wall assembly. (Julia Wiśniewska and Adam Miziołek, 2023)*

automation–preemptive configurations and performance optimizations that simplify the process at the possible expense of sophistication and fine-tuning capabilities. This is the case with the tool used for this coursework, which streamlined the image capturing and geometry creation process with the ability to backtrack and reconstruct geometries or update photographic datasets. Also, the choice of platform–a mobile phone app–added to the transparency of the development process and its 'unbearable lightness.' Following Kolb's classification, the 'experimentation' and 'observation and reflection' could be mapped to the very process of photogrammetric scanning, the selection of adequate lighting and environmental conditions, and an early evaluation of a photographic set used for the 3D model. The 'observation and reflection' component, and to some extent 'experimentation', occurred during the off-site phase when students were processing 3D scans in geometry and texture editing software, such as Adobe Substance 3D Painter. This phase was also associated with the transition to the 'formulation of abstract concepts and generalizations' stage as the immediate context of the scanned monument was trimmed and organized. However, the majority of the concept abstraction and generalizations were executed in the visualization phase discussed earlier.

Kolb's classification [Kol14] mapped differently to Study One where the 'observation and reflection' stage was already present in the initial sketching with dimension rationalization and abstracting of the overall form of the tombstone. The process forced students to an ongoing reflection– constant observations, comparisons of measured data, checking the accuracy of geometry and correcting, which resulted in a need for the abstraction of complex details. The same interference of the 'experimentation' phase and 'observation and reflection' phase appeared during 3D model development based on hand-made sketches and 2D documentation prepared earlier.

5.2. Automation Bias

The quality produced by photogrammetry tools exceeded what students usually associated with the 3D modeling and digital geometry output. This caused students not to question the outputs and

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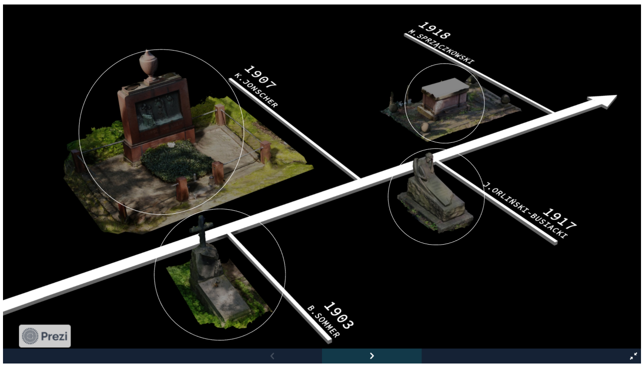

Figure 9: *Hierarchically structured Prezi presentation showing the landing page with multiple monuments. Each individual monument leads to photogrammetric model, photographs, details, and descriptions (Agnieszka Jędruszek and Łukasz Polewczyk, 2023).*

Figure 10: *Game engine-based (Unity3D) environments enable interactive explorations. Composing individual 3D scanned elements opens up opportunities for narrative storytelling and the discovery of unexpected associations (Oliwia Sadomska and Pawel Nowak, 2023).*

not to pursue further refinements. Only 20-25% of those participating in the Study Two reflected critically on initial scans and initiated by themselves refinements or recapture. Another 20-30% were made aware of the shortcomings of their models and were asked to redo the original 3D scans. This confidence in the toolset, or perhaps intimidation of interfering with the ‘complete’ model, continued in the next phase of work where students were asked to refine the geometry, its complexity and materiality. There was a preference for redoing the initial scan rather than re-editing it in other software. This was partially a result of the uneven familiarity with various software tools that were necessary for the effective pipeline. However, there was also a sense of a complex and complete model that discouraged additional editorial interferences. This reliance on the toolsets combined with the reduced level of skepticism–questioning technology outputs by students–may be part of a broader phenomenon of the blind trust of technology also referred to as the automation bias or automation complacency [PM10]. In this case, the technology often becomes a crutch or an autopilot rather than an empowering tool that ushers qualitatively new opportunities. This may have been in play to a certain degree with this group of students.

Another observation showed that students had a hands-off approach to the object of scanning. When a bush or a tree branch overhung or touched a tombstone and made it difficult to capture 3D geometry properly, the majority of students did not rearrange the surroundings to extract a pure form of the investigated artifact. However, during Study One, students utilized a conventional approach of the ‘creative license’ to isolate the depicted object and be selective of which surrounding elements were brought into the final documentation drawings.

5.3. Primary versus Secondary Sources

An important distinction between the documentation process of the first and the second study lies in the level of interpretative versus replication work that can be further extended to whether the documentation work should be considered the primary versus secondary data source. In the case of the first project, students used a direct observation and measurement method to develop drawings. This approach is necessarily an interpretive process as the act of drawing is associated with a selective abstraction of reality. With measurements taken on-site and later translated to scaled drawings, these are taken selectively with the assumption of orthogonal and parallel lines. Dimensional differences or out-of-line placement in the analog interpretative process are often rationalized and conformed into more ‘consistent’ and ‘clear’ drawings. This division into primary and secondary sources lends itself well to the dichotomy proposed by Vasari between *imitazione* (documentation) and *invenzione* (interpretation) with its implication for the creative use of these tools. In the educational context, an introduction of digital tools that increasingly provide automated, if not autonomous, capabilities may remove interpretative skills (learning objectives) from the curriculum. This may require a corrective intervention to provide additional opportunities for synthetic and interpretative (creative) contributions, as it was with the structuring of the second study deliverables. An important feature of the second study pipeline was its broader take on the materiality of investigated artifacts. Photogrammetric technology opens the discussion to the environmental and chromatic characteristics: an understanding that the perception of the object changes based on the lighting conditions or the season (interpretative) in addition to more factual material and textural attributes.

Traditional historical preservation documentation, often associated with an analytique drawing style of the 19th century, represents a secondary data source as the documentation contains a layer of interpretive observation of the original artifact. With digital 3D scanning technologies (photogrammetry) these documentations become primary data sources that preserve a high level of authenticity of the original artifact relatively unfiltered by the documentation creator. While for a researcher access to unfiltered primary sources is beneficial and essential, in the context of education, and broadly for content dissemination, interpretive and synthetic layers

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are crucial as they extend documentation to narrative and projective territories. For this reason, the second study emphasized the use of previously discussed presentation techniques in the context of photogrammetric scanning to introduce interpretive and synthetic thinking.

5.4. Curriculum Evaluation

No curriculum evaluation was conducted for Study One in 2013. However, it was clear from observing the students' participation in the course's various components that their collaboration with the city museum and presentation of their work to the local community were sources of satisfaction. In 2023, a curriculum evaluation was conducted for Study Two, which consisted of the following two components: (1) self-evaluation by the faculty based on the experience with comparable courses and assignments and (2) a qualitative student survey with open-ended questions.

The survey revealed that all participants had positive experiences in the course, with the majority believing that course participation improved their professional skills. The approach to conducting the course was perceived as innovative by most students. The course aligned with nearly everyone's expectations. Most participants reported that attending the course helped them understand the principles of digital photogrammetry and its application in architecture as well as the advantages and disadvantages of using it for architecture and monument preservation. Moreover, the majority confirmed that they had gained knowledge in creating 3D models using digital photogrammetry.

There were three questions related to the course and two related to photogrammetry: (1) How would you improve the organization and topics of the classes? (2) What part of the classes was most valuable to you? What did you get out of them? (3) What caused you the most difficulty in understanding the material and completing the project? (4) How would you compare photogrammetry to other computer techniques as a tool for surveying architectural and conservation projects? (5) How do you perceive the future of photogrammetric techniques in architecture and historic preservation?

In response to question 1, it was suggested that more time should be provided to complete the task, as it was a frequent concern. The majority of the comments were highly positive and even enthusiastic, for example, "Some of the most captivating classes I have ever taken during my time at the university." Practical classes in the field were deemed most valuable by many respondents, with some also noting the final presentation involving participation from professors of other universities. Multiple respondents stressed the importance of digital photogrammetry skills in professional contexts. The participants were asked to identify the most challenging aspect of comprehending and executing the task. Responses varied between technical difficulties, the unexpected format of the final presentation, and a lack of clarity on how to prepare for it were cited.

Students compared digital photogrammetry to other tools and computer techniques, appreciating the speed and ease of obtaining a model. However, opinions were divided on the quality and accuracy of the resulting reproduction. When responding to the inquiry regarding the future of photogrammetry and its potential applications, the participants stated the significant increase in protecting and conserving monuments, such as virtual museums. They also agreed that this technology will continue to advance and gain popularity.

Based on the above answers, it is possible to indicate key benefits for students: (1) learning about digital tools and equipment, and setting up survey controls; (2) learning how to use software (point cloud processing) and setting up a central model, which is now the industry standard; (3) developing digital modeling skills (modeling from point cloud); (4) learning architectural history and heritage from the existing as-built building (and not only through historical sources); (5) learning architectural history and heritage 'by doing' and through personal engagement.

Furthermore, it can be observed that digital photogrammetry allows for reduced time for the form re-creation and increased time/opportunity for the interpretive aspects of digital heritage, as compared with Study One. However, students could have had more time for the synthetic part of the assignment. While students voiced concerns with some of the technical issues the overall results were positive. Limited knowledge of the 3D photogrammetry technology might have an unfavorable impact on the outcomes. A similar situation was experienced at the beginning of 'traditional' CAD when imagination was constrained by available tools and computer literacy. In reference to students' confusion in the final presentation, the authors would like to stress that this was intentionally left as an open-ended process to allow for free visualization expressions. This is because design curricula and architectural education do not only reflect the continued evolution (pace) of design tools/technologies but also emerging conceptual frameworks associated with these technologies.

6. Conclusions

The examination of two architectural teaching approaches utilizing 3D modeling and photogrammetry for historic preservation yielded multifaceted insights and challenges. Firstly, the integration of emerging digital tools in the curriculum provided an opportunity for students to engage with historic artifacts in innovative ways, reshaping conventional approaches to heritage documentation and visualization. However, this introduced a question of active learning in the context of increasingly automated digital tools. While these technologies streamlined processes and produced impressive results, there was a tendency among students to trust the outputs without critical reflection, leading to a potential automation bias or automation complacency resulting in reduced scrutiny of outcomes and diminished interpretative skills integral to the educational curriculum. This, in turn, highlighted a need for a balance between embracing technology and encouraging critical engagement to harness its full potential for creative visualizations and storytelling.

Finally, while digital tools present opportunities to preserve the authenticity of historical heritage and serve as primary data sources for future research, cultural and educational applications necessitate a conscious integration of interpretative and synthetic layers to provide broader societal impact and dissemination.

7. Acknowledgments

The authors express their sincere gratitude to all individuals and organizations whose contributions and support have been instrumental in the completion of this research. The research team extends heartfelt thanks to the research and teaching staff as well as students from the Institute of Architecture and Urban Planning of the Lodz University of Technology (TUL), the Society for the Care of the Old Cemetery; the City Museum of the City of Lodz, and the Lodz Lapidarium of Details for their invaluable guidance, assistance, and resources throughout the course of this study. Their unwavering encouragement and expertise have significantly enriched this work. The authors would also like to thank the University's Project Service Centre for administrative and financial support.

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