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PHOTOGRAMMETRY WITH LIDAR IPAD PRO

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Abstract

Digital documentation of cultural heritage is a field that has grown rapidly in the last few years. The technological advancements in computing and the increased collaboration between fields keep offering researchers new tools with which they can capture objects, monuments or even entire archaeological sites, thus permitting non-destructive visual and geometric research and reproduction. Due to this rapid pace at which technology is advancing, such tools are now also available to a much wider audience, through everyday handheld devices. Smartphone and tablet cameras have improved significantly, to the point where they can work very effectively in place of a Digital Single Lens Reflex (DSLR) camera, in a photogrammetry setup. Accurate 3D reconstruction of cultural heritage objects with a smartphone and a computer is now possible and accessible to a multitude of people. Students and educators can capture objects in digital format, which they can then use for research or presentations purposes, non-destructive experimentation or even working 3D models. Publishing houses and content creators that design educational content or serious games, can also take advantage of a fast and easy way to create accurate 3D models of real-world objects and incorporate them in their work. Some of the newer handheld devices, mainly Apple's iPhones and iPads, have incorporated Light Detection and Ranging (LiDAR) sensors, for use with Augmented and Virtual Reality applications. These sensors can also offer a great degree of accuracy when used for photogrammetry. In this study we compare the photogrammetric process as performed by the 2021 iPad Pro with the M1 processor, in situ, to a DSLR camera and PC setup. We test the speed of capturing and processing in each case, and we also directly compare the 3D models' points and faces, as a way to measure the detail present in the final output. We use the iPadOS Polycam application, which exploits the device's built-in LiDAR sensor, to perform in situ photogrammetry. At the same time, when capturing is complete on the iPad, and to avoid lighting variations between processes, we use a DSLR camera for photography, that is similar to the iPad's camera in Megapixel. We then have a recent PC with Agisoft's Metashape perform the off-site photogrammetric process. The results indicate that the M1 iPad can be very fast in processing and with a very high degree of accuracy, thus making it a viable replacement for a camera and PC setup, and a valuable tool that offers accurate mobile photogrammetry, while also providing a solution for budgetary constraints.

Keywords: Photogrammetry, iPad Pro, LiDAR, Augmented Reality, Virtual Reality, 3D Modelling

1 INTRODUCTION

Digital documentation of cultural heritage has become a field of great importance for researchers in the last decades. New technologies have enabled not only the professional documentation and scientific management and analysis of data, but also, the creation of interactive, user-friendly applications for touristic, educational and dissemination purposes for the general public [1][2].

Significant technological advancements have facilitated the 3d reconstruction of cultural artifacts, buildings, monuments, sites - and even intangible cultural heritage such as festivals [2] - as well as the use of such reconstructions in Virtual Reality (VR) and augmented reality (AR) applications [2][3][4][5][6][7]. The most common non-invasive techniques, that have been used since many years for professional 3d data acquisition of cultural heritage, are terrestrial laser scanning (TLS) and photogrammetry.

Recently, smartphones, tablets and low-cost sensors are being considered as alternative techniques of data collection, that could facilitate the work of researchers in the field and also provide a solution to budgetary constraints [7]. The versatility, portability and ease of handling of such devices are the main factors for the recent boom in professional or amateur use of them as 3d recording instruments [8]. Moreover, the technological advances regarding the built-in cameras and the improved software have increased the quality of images captured with smartphones, thus the quality of 3d models generated from these images [8]. In 2020 Apple released its first iPad and iPhone with built-in LiDAR (Light Detection and Ranging) sensor, mostly for VR and AR applications [9][10]. However, the use of this sensor for 3d documentation purposes can have advantages, regarding speed, portability and low cost.

Especially in education, the use of new technologies combined with the traditional educational approaches can give a great advantage to students. In the last few years, e-learning, virtual classrooms and interactive VR and AR applications are integrated into the pedagogical techniques not only in universities but also in secondary education [8][11]. According to educational technology (edtech) theories, students can benefit from these classroom technologies, acquiring deep knowledge and skills that would be difficult to have with traditional theoretical presentations and lectures, and also develop critical thinking through interaction with digitized real-world objects [11]. Thus, students may enhance their academic performance and career development.

Archaeology is a field of study which requires the use of such edtech tools for better understanding, researching and documenting of tangible and intangible aspects of past civilizations and cultures. However, it is noted that there is limited access of archaeology students to digital technologies in many universities. Regarding 3d data acquisition and 3d modelling of cultural heritage for educational purposes, the costs of professional instruments and software may be inhibitory factors for many educational institutions to acquire [11]. In this case, the integration of smartphones and tablets in the educational process can provide a cost-effective solution, and also a great instrument for better engagement with the content of the lesson, as students are particularly familiar with their functions [8].

Moreover, not only educators but also students can participate in the creative process by capturing objects in digital format, which they can then use for research or presentation purposes, non-destructive experimentation or creating 3D models. Publishing houses and content creators that design educational content or serious games, can also take advantage of a fast and easy way to create accurate 3D models of real-world objects and incorporate them in their work.

The focus of this paper is to test the integrated lidar sensor on Apple's new iPad Pro in 3d scanning of cultural heritage, and to compare the results with photogrammetry using a digital camera. The main aspects of comparison are geometric precision and level of detail of the 3d model, time and cost of the procedure, and ease of use of the device. The aim of this study is to assess if the commercial-grade lidar sensor can be used for professional 3d cultural heritage documentation.

2 METHODOLOGY

We examined a total of four objects, two statues and two sculptures, referred to as Statues 1 and 2 and Sculptures 1 and 2 for convenience, all located on public roads in Thessaloniki, Greece. The research aim was to compare two scanning methods: 1) using the iPad Pro and Polycam LiDAR 3D scanning, and 2) using a DSLR and PC system that uses Agisoft Metashape.

Initially, we photographed and scanned each object separately. All objects were captured with both methods, in sequence, on the same day, to avoid variations in lighting conditions. The top of the objects was too high to be photographed by a person standing on the ground, making that the only area not captured. Photographs were shot at a stable focus and ISO, with a high f stop and an approximate 70% overlap. Data acquisition times were similar, in the range of 12 to 15 minutes, for both cases.

We did also perform the same processes on the PC, using pictures taken with the iPad Pro rather than the DSLR, for one object only, Statue 1. This was done in order to determine whether the specific camera optics on the iPad had a significant impact. For these tests we used the Halide app, again at a stable focus and ISO, with a high f stop. The total times were similar, with a deviation of 1m 28s to -14s, so we believe this to be a non-factor in this testing process.

After the data acquisition was completed, processing was performed separately for each method.

On the iPad Pro, all processing took place in the Polycam application environment. For all objects, the same settings were used: Depth Range was increased to the maximum of 5 meters, Voxel Size was reduced to the minimum of 9 mm, Simplification was at 0% and Automatic Crop was on.

All photos taken with the DSLR were transferred to a PC and imported into Agisoft Metashape, where the photogrammetric processing took place. We initially considered 3 groups of settings, namely medium, high and highest, named Ultra-High in some options. We eventually decided to test only on the highest possible levels, while testing the one sculpture only on medium, since we had the largest number of photos for that particular object, approximately 100. When aligning the photos, Accuracy was increased to the Highest. Building the Dense Cloud, we increased the quality to Ultra High, and when building the Mesh, we increased the Face count as high as possible without entering a custom value.

Models were then extracted from both the iPad Pro and the PC in ply format and inserted in Cloud Compare. The final comparison was a direct comparison of points and faces of the final models. Below in Fig. 1 you can see a flowchart of our methodology for both cases.

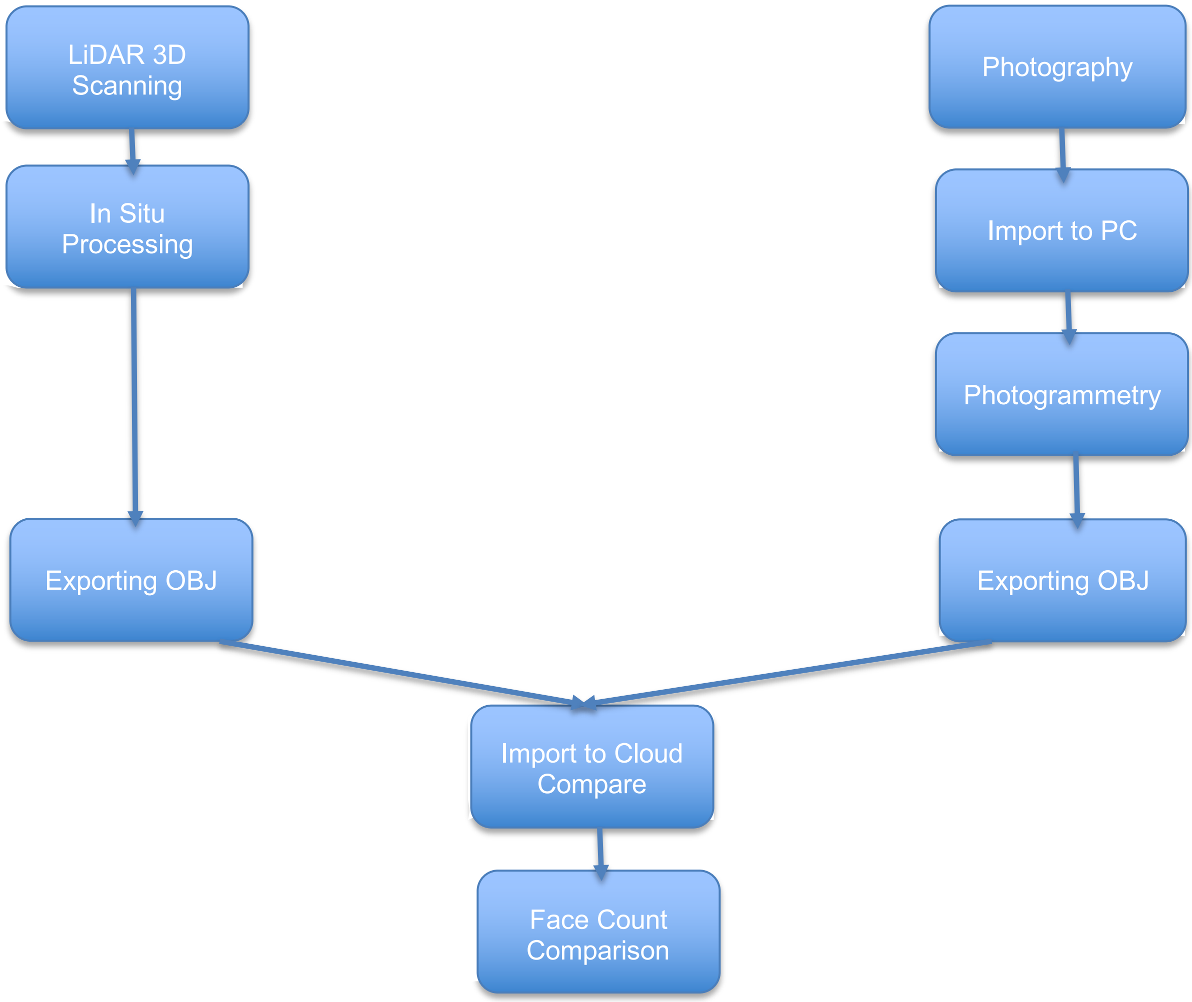

Figure 1. Methodology flowchart.

3 RELATED WORK

The techniques and instruments of 3d reconstruction are the main subject of several researchers over the last years. The most recent studies focus on new low-cost sensors and devices, in order to examine if they can be used professionally for documentation, comparing them with consolidated techniques such as terrestrial laser scanning, photogrammetry and mobile mapping systems. Each of these techniques has advantages but also limitations, regarding speed, accuracy, cost, time and ease of use.

Terrestrial laser scanning (TLS) is a range-based technique using active sensors for the acquisition of accurate metric and colorimetric data of models with complex geometries in a short time [4]. After the scan, the data have to be processed using the specialized software in order to generate the corresponding point cloud.

Photogrammetry is based on image matching methods. A specialized software extracts matching features from multiple overlapping photographs captured by a camera moving around the scene of interest, then it generates 3d point clouds and subsequently 3d models [1][3][12]. Although at first this technique required specialized staff for a professional outcome, the progress of digital photogrammetry and Structure from Motion (SfM) technique today allow everyone to use photogrammetry easily [12][13].

However, there are a few research studies based on data collection using mobile devices, such as tablets and smartphones. In these studies, the researchers use the integrated camera and LiDAR sensor on iPhone 12 Pro or 2020 iPad Pro for 3d data acquisition, mainly in the field of cultural heritage [7][9][10], but, also, in other areas such as forestry [14]. They compare the generated point clouds to those generated by professional devices, such as digital cameras and terrestrial laser scanners. Specifically:

[7] compared the levels of accuracy of the 3d data acquired using the camera on the iPhone 12 Pro and Nikon D5000 digital camera, by implementing the photogrammetric technique. They compared the dense clouds in terms of geometric and radiometric accuracy, and came to the conclusion that the iPhone 12 Pro camera provides satisfactory results, although it has slightly lower values than the digital camera.

[9] analyzed the point clouds generated by 2020 iPad Pro SSL compared to those created with photogrammetry using a Canon EOS 6D DSLR and terrestrial laser scanning with a FARO Focus X330. The 2020 iPad Pro SSL sensor was deemed sufficient, regarding geometric quality, for several 3d visualization, VR and AR applications but not for those which require high precision (mainly because of the presence of noise of the point cloud). Also, ambient lighting and the material of the object can affect the final result. In terms of cost, time and ease of use the SSL sensor has very good results.

[10] evaluated the 2020 iPad Pro SSL sensor in comparison to terrestrial laser scanning. They analyzed the metric characteristics of the point clouds, regarding resolution, density, precision, accuracy and noise. The overall assessment was that the SSL sensor has great potential for 1:200 architectural rapid mapping, since it can generate reliable 3D point clouds with low cost, ease of use and in limited time.

[14] compared the 2020 iPad Pro LiDAR sensor with a multicamera prototype named MultiCam, a hand-held personal laser scanner, the GeoSlam Horizon, and a terrestrial laser scanner, the FARO Focus s70. Although they focus on a different area, specifically forestry, than the previously mentioned researchers, their assessment showed that the SSL sensor results were comparable to those of the other instruments, with a big advantage being the fact that the point cloud is available right away in the field.

In conclusion, the researchers report that the built-in camera and LiDAR sensor have satisfactory results, compared to professional instruments, in geometric quality, time and cost of the procedure, and ease of use of the devices. Also, the portability and small size of the smartphone and tablet makes them a very promising innovative technology for cultural heritage documentation.

4 EQUIPMENT

The M1 processor on the iPad Pro was released in late 2020. It was revealed to be an 8-core CPU with an 8-core GPU and a 16-core Neural Engine. Marketed for AR usage, it promised a 50% faster CPU performance and 40% faster graphics performance. In comparison with the 2020 iPad Pro and iPhone 12 Pro optics, the specifications made public make it seem to have the same rear facing cameras and LiDAR sensor. We do not know of any changes in optics or otherwise, as they have not been publicized. For this particular comparison, we used a 2021 12.9” M1 iPad Pro with 8 GB of Ram and the Polycam application. Polycam is a LiDAR 3D scanner application, which works on a subscription model. We found 3D scanning to be very fast and easy to use, since it overlays a grid over areas it has scanned effectively and colors the areas it has not scanned yet or cannot, so that the user can edit that omission in real time by moving to a different angle, closer to the object or further away etc.

For the PC photogrammetry test, we used a Canon D450, a crop-factor 12 Megapixel DSLR, with a 18-55 zoom lens for photography, and a PC running Windows 11 for photogrammetry, with the hardware specifications shown below in Table 1.

Table 1. Photogrammetry PC Hardware Configuration.

Processor (CPU)	Intel i9 12900K
Random Access Memory (RAM)	16GB 4800Mhz DDR5 CL 40
Graphics Processing Unit (GPU)	Nvidia RTX 2070 8GB
Storage Drive (HDD/SSD)	M.2 Western Digital Black SN 850 PCI-E 4.0

We selected the newly released Intel Alder Lake i9 12900K, which has a hybrid core configuration of 8 high-performance cores and 8 power-efficient cores, similar in architecture to Apple's M1. On many reviews and tests performed by various tech-focused websites, it often appears as the fastest desktop processor for photogrammetry. It is, however, a very new processor that introduces a new architecture in x86 systems, namely big.LITTLE architecture. We also opted to use DDR5 RAM, even though it is yet not as fast (latency-wise), nor thoroughly tested and widely used as DDR4, since it is the type of memory that will be used in newer systems.

5 RESULTS

In Table 2 below we present the total processing times, for each method and object.

Table 2. Total processing times.

	Sculpture 1		Sculpture 2	Statue 1	Statue 2
Settings	Ultra-High	Medium	Ultra-High	Ultra-High	Ultra-High
PC	7h 8m 14s	3m 36s	28m 40s	12m 15s	10m 53s
iPad Pro	58s		1m 2s	27s	29s

We have to note here that the approximately 7h it took for Sculpture 1 on Ultra-High was consistent. We tested it a total of three times and every time had roughly the same result of 7 hours. Since this occurred consistently, we narrowed it down to two possible causes. It could be a hardware limitation that occurs due to a much higher photo count, so perhaps since the photos could not all be loaded onto the memory and processed simultaneously, the photogrammetry had to be performed in parts and that slowed down the overall process. It could also be due to the number of photos, where some might have been containing information not seen in others, such as a passer-by or car that was moving in the nearby street, and this much detail delayed the process.

In Table 3 the detailed time of processing for each phase on the PC is shown for Sculpture 1 only, as an indication of which processes took the longest. For the iPad Pro, the time is the total processing for the mentioned settings.

Table 3. Time per process.

System	Process	Quality Settings		Time
PC & Metashape	Align	Highest		16s
	Build Dense Cloud	Ultra-High		7h 1m
	Build Mesh	High		5m 51s
	Build Texture	-		1m 7s
				7h 8m 14s
iPad Pro & Polycam		Depth Range	6 meters	58s
		Voxel Size	10mm	
		Simplification	0%	
		Automatic Crop	On	

Table 4 below presents the same processing times for Sculpture 1, on medium settings.

Table 1. Caption for the table.

System	Process	Quality	Time

		Settings		
PC & Metashape	Align	Medium		15s
	Build Dense Cloud	Medium		1m 17s
	Build Mesh	Medium		1m 35s
	Build Texture	-		29s
				3m 36s
iPad Pro & Polycam		Depth Range	6 meters	58s
		Voxel Size	10mm	
		Simplification	0%	
		Automatic Crop	On	

Finally, Table 5 directly compares the face count, as indicated in Cloud Compare for each model.

Table 5. Face count per system.

	Sculpture 1		Sculpture 2	Statue 1	Statue 2
Settings	Ultra-High	Medium	Ultra-High	Ultra-High	Ultra-High
PC	8,932,733	211,065	5,611,890	3,100,244	5,324,361
iPad Pro	421,594		428,790	157,929	278,279

Overall, we can see that while the iPad Pro is much faster, in face count it remains far below the same process on a DSLR-PC system, in very high settings.

6 DISCUSSION

We performed a total of four photogrammetric processes, not counting repeats to examine the 7-hour oddity. The level of detail, which we compare subjectively, considering the number of faces as indicators, was fairly close in medium settings, while not close at all in Ultra-High, in favor of the DSLR-PC system. The processing time was also widely different, with the iPad Pro coming out ahead. We recognize that comparing points, faces and processing time is not overwhelming evidence of the superiority of either system. It is, however, a strong indicator that both processes have their merits.

From table 5 above, we can see that the iPad Pro performed much better in the medium settings, getting nearly double the number of faces much faster. On the other hand, in Ultra high settings, the resulting models from Metashape had many more faces. This difference doesn't take into account that the iPad Pro effectively scanned only the objects, while the photogrammetric process has captured some of the ground, as well as background objects total, though that alone will not reduce the face count to the iPad Pro levels. For example, as soon as we cleaned statue 1 from any foreign objects, such as trees and ground, the face count rapidly dropped to 990,269. Fig. 2 and Fig. 3 below show the results for Statue 1 from each process, after deleting the foreign objects in the second image. One other important issue, and where we believe the iPad Pro loses in face count significantly, is height. The cultural heritage objects we selected are all quite high, therefore we could not reach the higher parts, such as the face in Statue 1, which is at approximately 3.5 meters from the ground. When we zoom in on the face of the iPad Pro model, we see very little detail, as opposed to the base where the plaque is. The photogrammetric process does not have that limitation and effectively collects much more information for every area that is seen in the photographs. That offers a much higher face count.

Figure 2. iPad Pro 3D model of Statue 1.

Figure 3. Photogrammetric model of Statue 1.

The time-comparison results were unexpected, if we keep in mind that the iPad Pro process is performed on the spot. The performance of the M1 was surprisingly fast while also being much easier, compared to the PC based process. In our opinion, this is probably a direct benefit of the integrated GPU cores on the M1 processor and its overall architecture. In the case of Sculpture 1, we saw a much higher processing time in building the dense cloud, which we can only attribute to the much higher number of photos we had for that object. We do not take the 7-hour result into account, as the cause behind this delay is not known. Even so, considering the 10, 12 and 28 minutes of the other cases, 30 seconds to 1 minute on the iPad is quite impressive.

We need to take into account that the overall process on the PC takes longer than simply processing time, since it can include anything from returning to the office, to transferring the camera photos to the PC and anything that might be required in-between, such as having to photograph the object again due to a sudden lighting change, a change in focus or even a person that passes in front of the camera. On the other hand, the iPad Pro completes the whole process on the spot, with no other actions required. Table 6 below presents total time, with 10 minutes added to every PC process, so as to represent the higher preparation and execution time of the whole workflow. We did not include anything for travel times, but they do need to be considered.

Table 6. Time per process.

	Sculpture 1		Sculpture 2	Statue 1	Statue 2
Settings	Ultra-High	Medium	Ultra-High	Ultra-High	Ultra-High
PC	7h 18m 14s	13m 36s	38m 40s	22m 15s	20m 53s
iPad Pro	58s		1m 2s	27s	29s

We also need to note that the Alder Lake i9 processor is very new, as is the big.LITTLE architecture in x86 systems. Windows 11 tries to alleviate some of the problems with the new architecture by including the new Thread Director, which was designed to manage the cores of Alder Lake processors effectively. DDR5 is also very new and still has low latency (the RAM we used had a CAS Latency of 40, running at 4800 MHz), which can sometimes make it slower than DDR4, as seen in various performance tests. Overall, it is our opinion that Alder Lake based systems with DDR5 RAM will get faster as the software is improved to incorporate their unique features. We should keep in mind that the RTX 2070 is a 2018 GPU, an older model than the current 3000 series GPUs. A current generation GPU could show a significant performance increase, though that comes with an even higher price. Overall, the performance of the DSLR-PC system will definitely improve over time, as software is modified to better use the processor cores. The iPad Pro is definitely an improvement and the M1's performance could also increase with software modifications, though we expect a newer model with better optics and processor will close the gap between the two methods.

We need to consider the two methods as to their flexibility. A tablet offers much more portability and overall flexibility than a combined DSLR and PC system. It has a fairly large battery, larger than most DSLR cameras, and is of similar weight (from 466 grams on the 11-inch Wi-Fi model to 685 grams on the 12.9-inch Wi-Fi & Cellular model) to the DSLR (524 grams). The whole process is performed on the spot, with the option of adding to the model after the initial process has taken place. This offers the ability to better capture areas that were missed or omitted, or even capture a very large object in parts. On the other hand, it remains a tablet, therefore lacking expansion options and connectivity to a certain degree, and it runs iPad OS, a tablet-focused operating system, which heavily limits software use.

Finally, from a budgetary standpoint, the iPad Pro is currently the most budget-friendly solution, considering the 11-inch 2021 model starts at $799 at Apple Stores, with the Polycam subscription at 39.99€ for one year. The PC used in testing costs approximately $2800 (as seen on Newegg.com), not considering peripherals such as a monitor etc. We have to note here that this price is hugely impacted by the current global shortage on chips in general, and GPUs in particular. Therefore, the inflated, at the moment, prices for those specific components skew the economic considerations towards the iPad Pro. This is a budgetary constraint that can have significant impact for professionals in the field, since the budget conscious choice would be the iPad Pro, though perhaps the PC would serve better in the long term, due to software flexibility.

7 CONCLUSIONS

The aim of this paper was to demonstrate that the LiDAR sensor on the iPad Pro makes it an excellent portable photogrammetry tool for cultural heritage capture, rather than conclude on which method is better. The iPad Pro can offer on-the-fly 3D models of very good quality, that can be exported in a multitude of formats through Polycam. It is also the faster option by far, offering above medium quality results in that time, compared to the DSLR-PC method. On the other hand, photogrammetry performed on the DSLR-PC system offers much more geometrically accurate results, and could potentially go higher with more photos taken per object or tweaked settings to match specific use cases, though more photos would also increase processing time.

Overall, speed, ease of use and low cost of the iPad Pro make it a great instrument for 3d data acquisition and 3d modelling for educational purposes. It can be easily used not only from professionals but also from amateurs, and its portability and flexibility prompt the spontaneous capture of images. Therefore, students and educators can create their own models of cultural heritage objects, present them in the classroom and use them for research or experimentation.

Future studies should be with shorter objects, that we could reach, such as a sarcophagus, to determine whether the face count difference seen in this study is indeed all due to height. We could also do a similar comparison with a higher grade DSLR, perhaps with a higher Megapixel count or even a Full Frame sensor. The same comparison could also be performed with an iPhone 13 Pro rather than an iPad Pro, devices that were both introduced in 2021, in order to note any differences, perhaps in the LiDAR sensor or investigate the potential in the A15 Bionic chip on the iPhone 13 Pro and the actual impact of the M1 processor on the iPad Pro.

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