New Low-Cost Technologies for Easy Documentation of Smaller Monuments and Analysis of their Outputs

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Keywords: Low-cost Technology, Pix4Dcatch, 3DSurvey, Smartphone, RealityScan, Agisoft Metashape.

Abstract

This study explores the potential of low-cost methods for documenting cultural heritage using modern mobile technologies, focusing particularly on photogrammetry, videogrammetry, and the integration of LiDAR sensors in smartphones. As traditional 3D documentation methods like terrestrial laser scanning and professional photogrammetry are often costly and inaccessible, especially in field or emergency contexts, affordable alternatives such as smartphone-based applications (e.g., Pix4Dcatch, RealityCapture Mobile, and Agisoft Metashape) are increasingly being adopted. These tools utilize RGB imagery, LiDAR, and GNSS/RTK support to produce 3D models of varying precision and scalability. Pix4Dcatch, particularly when paired with the viDoc RTK rover, stands out for its ability to generate accurate, georeferenced LiDAR-enhanced point clouds, while RealityCapture Mobile uses LiDAR to improve internal pose estimation but does not export LiDAR data. Videogrammetry, enabled by software like 3DSurvey, offers another cost-effective approach by extracting frames from video footage. Several case studies demonstrate the varying accuracy of these techniques, comparing models produced by smartphone-based systems against professional laser scanning benchmarks. Results show that while mobile solutions offer significant advantages in portability, speed, and ease of use, they are limited in range and precision—especially beyond 10-15 meters. However, within short distances (under 5 meters), their performance can rival or exceed that of professional laser scanning for certain use cases. This varies depending on the camera used. The findings confirm that these mobile and low-cost technologies are practical for preliminary documentation, education, and rapid-response efforts, especially in cultural heritage preservation under resource constraints.

1. Introduction

1.1 Low-cost documentation of cultural heritage

Low-cost methods of documenting monuments offer significant advantages. Preserving cultural heritage through documentation is essential, especially in regions at risk from conflict, natural disasters, or neglect. While traditional methods like LiDAR and high-end 3D scanning are effective, they are often prohibitively expensive (Hassani, 2015). Fortunately, several low-cost alternatives have emerged that balance affordability with accuracy. They can be used by non-experts, serve as quick documentation methods in the field where situations change rapidly, such as in archaeology or heritage restoration, or as handheld technologies that can be taken virtually anywhere. This involves the use of digital cameras or fast phones and photogrammetric software, possibly in conjunction with RTK GNSS or lidar sensors. These methods are affordable and accessible and allow heritage professionals to quickly and accurately capture detailed data without the need for expensive equipment (Lee et al, 2022). The integration of photogrammetry and limited laser scanning provides high-resolution textures and precise geometric accuracy (Gautier et al, 2020). This approach not only preserves architectural details but also allows the creation of realistic digital models suitable for virtual and augmented reality applications. Furthermore, these methods can be rapidly deployed, making them ideal for documenting emergencies or in hazardous areas (Pavelka et al, 2025, 2023).

2. Special hardware

The viDoc RTK rover for PIX4Dcatch is specially designed for accurately capturing 3D spaces from the ground with selected iOS devices equipped with LiDAR sensors, but also works with other selected models, including Android devices. It supports RTK positioning for enhanced accuracy. Another system producing 3D data is the 3Dsurvay software; it is possible to use a common smart phone connected with additional RTK GNSS device (Fig.1, 2).

Figure 1. viDoc RTK rover, with smartphone or tablet

Figure 2. Smartphone with connected RTK GNSS, 3DSurvey

https://doi.org/10.5194/isprs-archives-XLVIII-M-9-2025-1167-2025

Figure 3. Coloured point cloud from viDoc RTK GNSS

3. Smartphones

3.1 Hand-held photogrammetry

Today's era allows you to take high quality photos with ordinary smartphones. It goes without saying that a professional digital SLR camera with a fixed focal length certainly provides much better results, but for many applications a smartphone will sufficient. This is especially true for photographing smaller objects and quick documentation, and will be useful, for example, in archaeological excavations or restoration work or routine errands where speed of acquisition and automatic processing are an advantage. The processing of the photographs can be done either with classical photogrammetric software such as Agisoft Metashape, RealityCapture, Zephyr etc. or with a special application directly for smartphones.
Here Pix4Dcath application with cloud processing is available (https://www.pix4d.com/product/pix4dcatch/); the data are directly sent to the cloud, and in some dozens minutes the result is received back. Similar software is RealityScan (https://www.realityscan.com/en-US), developed by Epic Games and works on cloud. This app is tailored for high-resolution scans of cultural artifacts and integrates well with platforms like Sketchfab for sharing and visualization. Both apps are intuitive and guide the user through the documentation process, showing the parts of the object already captured. Pix4D catch with lidar sensor has the advantage of creating a scale model (Fig.3). The comparison with the static measurement using the Trimble X7 laser scanner was very good in this case. The ViDoc model was faster, cheaper and with higher detail and better texture. However, this is only valid for close objects up to about 5m and if there is good quality RTK reception and good illumination.
Of course, today next applications can be found like Polycam (iOS, Android, https://poly.cam/). It offers both LiDAR and photogrammetry modes, making it suitable for scanning interiors, sculptures, and museum exhibits, KIRI Engine (iOS, Android, https://www.kiriengine.app/) is a next user-friendly photogrammetry app that allows users to take photos from multiple angles and generate 3D models in the cloud. Modern are nowadays AI supported softwires or applications like Luma AI (iOS). It uses Neural Radiance Fields (NeRF) to produce photorealistic 3D models of small cultural objects, such as statues or tools, but in many cases, it is not a completely true model reflecting the actual reality (Remondino et al, 2023).

Smartphone apps for 3D scanning offer accessible and affordable tools for cultural heritage documentation, but they come with several limitations that can affect the quality and reliability of the results. First, they have a limited accuracy and resolution. Smartphone-based LiDAR and photogrammetry often lack the precision of professional-grade scanners. Smartphone cameras are sensitive to lighting conditions. Poor lighting can introduce noise or shadows that degrade the quality of the 3D model. This is especially problematic in indoor or low-light heritage sites. High-resolution 3D scans require significant processing power and storage. Smartphones often work with the power of cloud solutions. Smartphone LiDAR sensors (available on some iPhones and iPads) have a limited range—typically around 5 meters. This restricts their use for scanning large structures or open-air archaeological sites. And an important thing, some apps restrict export formats or require paid subscriptions for full functionality. Due to their lower accuracy, smartphone scans are generally not recommended for structural monitoring, deformation analysis or very precise architectonical drawings. Despite these limitations, smartphone apps remain valuable for preliminary documentation, public engagement, and educational purposes. They are especially useful in resource-limited settings or for rapid-response documentation. (Boboc at all, 2018)

3.2 Videogrammetry

The principle of videogrammetry is conventional terrestrial photogrammetry, the difference is that the images are automatically or manually created from the video by software (e.g. 3DSurvey). However, this is only allowed by modern technology, where smartphones have sufficient video resolution and automatic extraction of images from video by software
Case studies were conducted to compare the advantages and disadvantages of low-cost equipment for documenting heritage objects. A selected small object was scanned with a Trimble X7 precision laser scanner as a reference and the results were compared with Pix4Dcatch, Agisfoft Metashape and RealityScan. Accuracy, range and speed of acquisition and data processing were compared. Within short distances (under 5 meters), the performance of photogrammetrical low-cost can rival or exceed that of professional scanning for certain use cases.

4. Data processing

Today's creation of 3D models in photogrammetry is based on calculating the interior and exterior orientation of cameras using Structure from Motion (SfM) technology, which generates a sparse point cloud. Subsequently, Multi-View Stereo (MVS) is used to generate depth maps from which a dense point cloud and subsequently a polygonal mesh can be reconstructed. In some cases, the mesh can be generated directly from the depth maps, which can be computationally more efficient. The resulting model is often completed with texture derived from the original images.
This process is typical for desktop applications, especially the best known Agisoft Metashape (Fig.4)

https://doi.org/10.5194/isprs-archives-XLVIII-M-9-2025-1167-2025

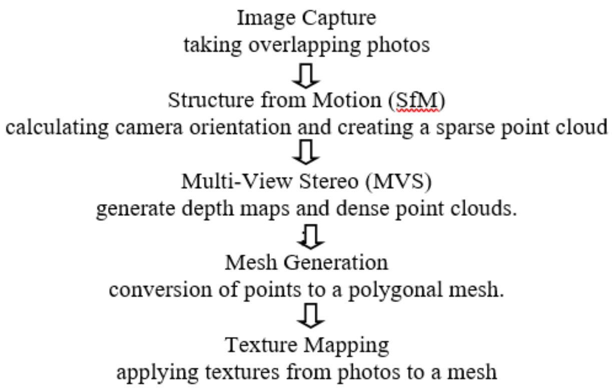

Figure 4: Flow chart of a typical automated photogrammetrical process for creating of a 3D model

Smartphone apps have started to develop in recent years. Among the best known are Pix4D catch and RealityCapture mobile (RCM). The main problem is working with a mobile phone, which does not have the power of a good computer. Therefore, the processing takes place on the cloud, where the data is sent and processed. The processing process and parameters cannot normally be influenced, which is a major difference from a local installation on a personal computer, where the parameters can be selected in various ways. Therefore, the results cannot be objectively compared with each other, but it is difficult to assess the quality of the result and the predictive value of the generated model.
When using the application, the object is continuously scanned. Individual frames are either generated from video or taken at low resolution in rapid succession. If a lidar sensor is present, the image data is combined with a coarse spatial model of the object to give the model scale. If additional GNSS RTK hardware is not available, low-resolution GNSS position sensing with an accuracy of 3-5m in position is used, which is insufficient for accurate scaling. Therefore, the best results are obtained when the GNSS RTK module-oriented imagery is combined with a lidar sensor.
RealityCapture Mobile (RCM) can use Apple’s LiDAR sensor (on iPhones/iPads like the iPhone 12 Pro and newer) to:

- Improve camera pose estimation (i.e., it helps with positioning the camera more accurately).
- Help stabilize the image capture process in feature-poor environments (e.g., smooth walls or dark surfaces).

This use is only for internal processing during image capture. It does not export the LiDAR data itself or generate a LiDAR-based point cloud like Pix4Dcatch does. RCM does not generate or export LiDAR point clouds. RealityCapture (desktop) cannot process raw LiDAR point clouds as a standalone input for reconstruction — it’s designed for photogrammetry (image-based) workflows. Even though RCM doesn’t export LiDAR point clouds, having a LiDAR-equipped device provides three advantages:

- Improved Camera Calibration
  LiDAR assists with the camera’s internal understanding of distance and angle, improving positional accuracy.
- More Reliable Tracking
  In indoor or featureless areas (e.g., walls, floors), LiDAR helps keep tracking accurate, reducing motion blur and drift.
- Better 3D Reconstruction (indirectly)
  Because image alignment is more accurate, the final mesh you reconstruct in RealityCapture (desktop) will likely be cleaner, with fewer alignment errors or holes.

RCM can export a mesh model only.

Pix4Dcatch actively uses the LiDAR sensor on supported iPhones and iPads (e.g., iPhone 12 Pro and later) to capture:

- High-resolution LiDAR point clouds
- LiDAR-enhanced camera pose tracking
- Combined photogrammetry + LiDAR datasets

Pix4Dcatch stands out because it uses both RGB images and LiDAR depth to produce accurate and georeferenced 3D models.

5. Case projects

To find out today's possibilities of quick and cheap documentation of a smaller historical object, the object in Střítež u Jihlavy (Czech Rep., 49.4582511N, 15.6127928E) was selected. The object was documented by videogrammetry and processed in 3DSurey software and further using ViDoc Pix4Dcatch system. Both methods use a smartphone, Pix4Dcatch uses a lidar sensor in the phone and an additional GNSS RTK device. Both technologies take only about three minutes each to document an object. For georeferencing, 11 geodetically measured ground control point were used. The ViDoc model after transformation to GCPs had deviations on them from mm to 1.9 cm, the 3DSurvey videogrammetry model after transformation to GCPs had deviations on them from mm to a maximum deviation of 4.8 cm, Fig.5-9.

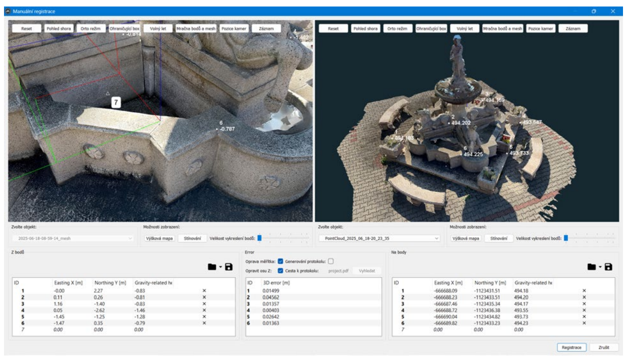

Figure 5. Finding point to check the accuracy of the model

The two models were compared against each other using five randomly selected points, with the ViDoc model being determined to be more accurate due to the georeferencing by GNSS RTK, the use of a lidar sensor, and the significantly more detailed point cloud obtained from the imagery. The point deviations were within centimetres; the results can be found in table 1.

Point ID	3D errors [m]	X error [m]	Y error [m]	Z error[m]
1	0.0156m	0.0026m	0.0149m	0.0037m
2	0.0237m	0.0148m	0.0184m	0.0015m
3	0.0232m	0.0189m	0.0113m	0.0073m
4	0.0254m	0.0100m	0.0224m	0.0063m
5	0.0162m	0.0114m	0.0004m	0.0115m

Table 1: Mean registration error 0.0104m, mean target registration error components 0.0115m, 0.0135m, 0.0061m, 5 correspondences found (fig. 4)

Figure 6: point cloud derived from videogrammetry, 3DSurvey, 2.3 million points, 616 photos generated from video

Figure 7: point cloud from ViDoc reduced on 5 million poins, 27 million points originally

Figure 8. Textured 3D mesh model, Pix4D catch https://cloud.pix4d.com/dataset/2254785/model?shareToken=d595786b-a5a2-4faa-b273-4e42e40bbdc6

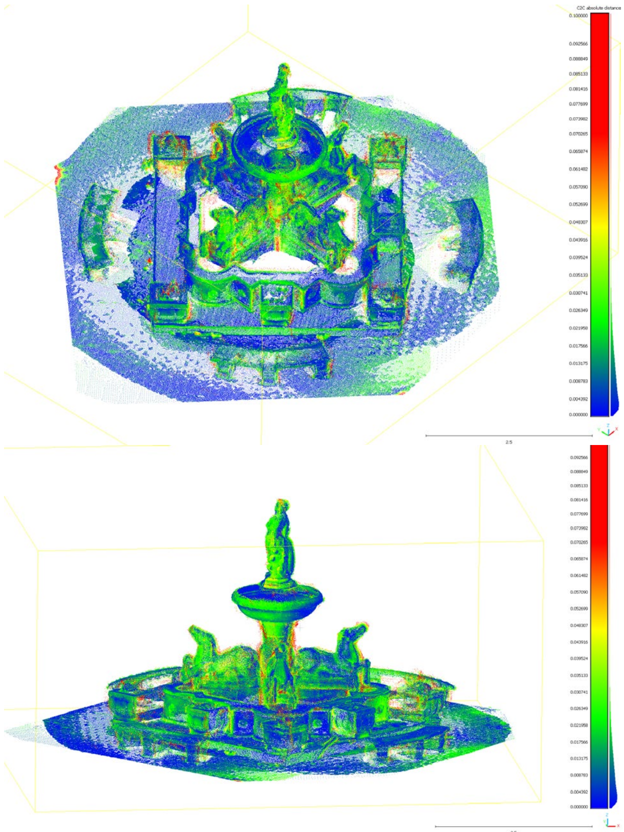

Figure 9: Output from CloudCompare software, differences between two models created by videogrammetry and ViDoc (as reference model); the colour legend is in metres

5.1 Unknown small gravestone in the forest

In this case, an unknown small artifact was documented in a forest in the Czech German border region with an unknown history. The object is in the Ore Mountains. The processing was performed by Agisoft Metashape, data was obtained with iPhone 12Pro, 4mm focal lenght,84 photos (3024x4032), typically 7.8Mb, dense point cloud consists of 62-million-point. The object is in Czech Rep., 50.3997411N, 12.9187464E, Fig.10-12.

Figure 10: Pix4D catch, iPhone 12Pro, 4mm focal length, 195 photos, approximately 1.6Mb supported with LiDAR device

Figure 11: RCM generated mesh, 600 thousand triangles

Figure 12: Agisoft Metashape, 1.3 million of triangles, 84 photos

5.2 Historical boundary stone

Furthermore, a model was made with various technologies based on a smartphone. The object is a three-boundary stone in the Ore Mountains., Czech German border, Boží Dar, Ore Mountains, Czech Rep., 50.4042367N, 12.9482075E.
First used technology was typical IBMR technology (image-based mapping and rendering) using Agisoft Metashape. It produces a very high detailed model based on original images, but without precise scale.
Results of the mesh model from different applications are shown in Figures 13-15, comparison with the most accurate model, which was the model from Agisioft Metashape software is shown in Figure 16, output from CloudCompare.

Figure 13: Agisoft Metashape generated mesh model, 118 photos, hand-held taken photos

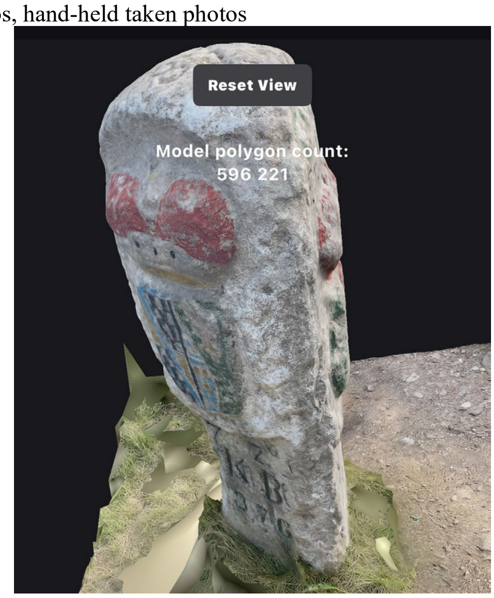

Figure 14: Next used technology was Pix4Dcatch, 356 photos automatically taken, approximately 1.5Mb each, supported with LiDAR device

Figure 15: RCM generated mesh model, 600 thousand triangles, supported with LiDAR device, optimized fully automatically taken photos

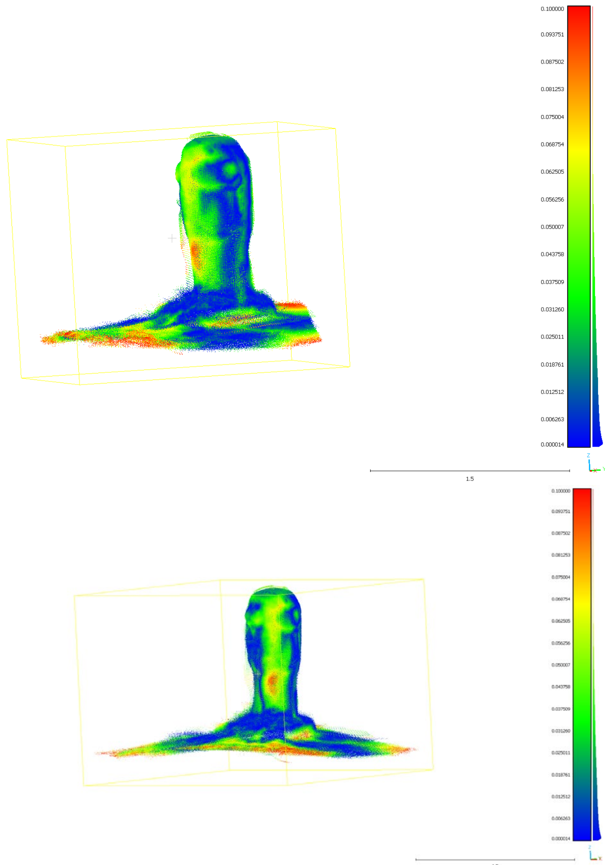

Figure 16: Output from CloudCompare software, differences between two models created by Pix4Dcatch and Agisoft Metashape (as reference model); the colour legend is in metres

5.3 Crete, Greece, historical wall relief

This wall relief is in Greece, 35.3698536N, 24.4756514E. First, the model was processed with Agisoft Metashape (20 photos, 10.6 million dense point cloud iPhone 12Pro, 4mm focal length) on a professional processing on Workstation, Intel(R) Core (TM) i7-4770 CPU @ 3.40GHz, 16,0 GB RAM, 64bit system.

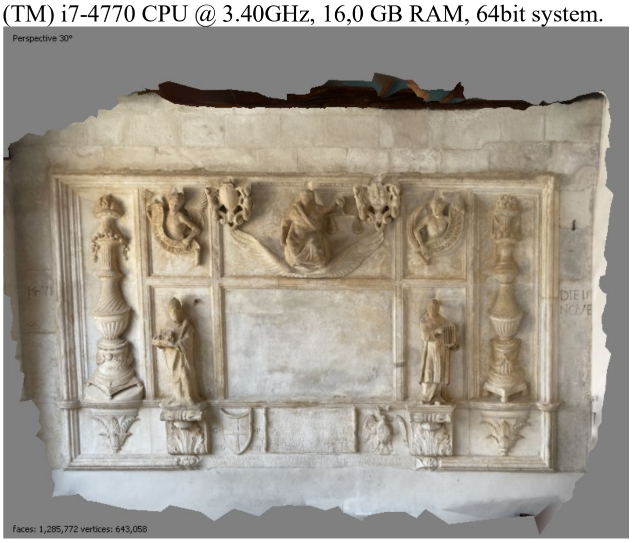

Figure 17: Agisoft Metashepe, 20 photos, 2 minutes capturing, 15 minutes of processing on workstation, meshed and textured 3D model 1.2 million triangles, 10.6 million points

Figure 18: A detail with sub-millimetre resolution, Agisoft Metashape

Next part focuses on comparing the results of point clouds from desktop (Pix4Dmatic) and mobile applications (Pix4Dcatch). In both cases, the inputs were photographs (232 photos) taken with an iPhone 12 PRO mobile phone with a lidar sensor. The point cloud processed in the desktop application was 68 MB in size and contained approximately 11.5 million points. The point cloud processed via the Pix4Dcatch application, which sends the captured data to the cloud for calculation, was 10.6 MB in size and contained 3.1 million points. The processing settings options in the Pix4Dcatch mobile application are very limited. The closest setting to this was the "optimal" quality option in the desktop application.

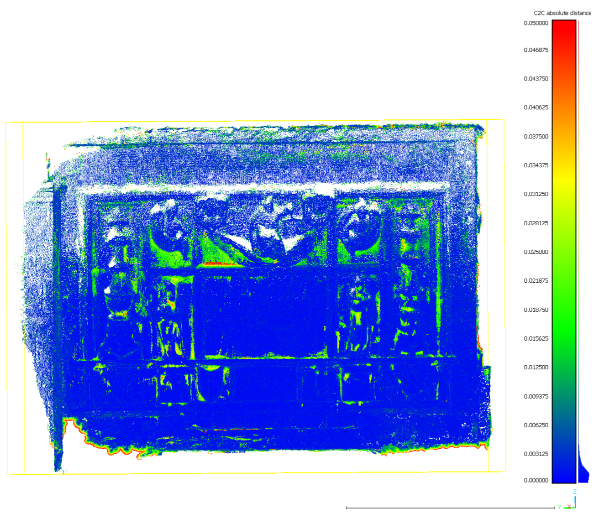

Figure 19: Pix4D catch, 232 photos, approximately 1Mb per image supported with LiDAR device

However, the final comparison of both point clouds in CloudCompare v2.13.2 shows minimal differences in cloud deviations. Deviations from the denser and more detailed point cloud from the desktop application show almost identical results. The point cloud from the mobile application shows a maximum deviation of 0.003 m in 95% of cases compared to the desktop application.

6. Conclusion

The results show that the above-mentioned low-cost technologies can be used with certain limitations, which mainly concern the distance from which the data is obtained. At distances greater than 20 meters, the accuracy is no longer sufficient for more precise work. On the other hand, photogrammetric methods are generally better and more accurate than professional laser scanning for very close objects within approximately two meters. The advantage of Pix4D catch is its connection to a smartphone equipped with a lidar sensor. This allows you to create directly scaled models, although the accuracy is limited by the range and quality of the lidar sensor. In general, capturing an object using individual images is actually scanning the object using a matrix sensor. This corresponds to data collection technology, where all parts of the object need to be scanned, and classic stereophotogrammetry is no longer widely used in these cases, although its principles remain the same.

Acknowledgments

This project was supported by the internal grant of the CTU in Prague SGS25/046/OHK1/1T/11

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