APPLICATION OF TERRESTRIAL AND UAV PHOTOGRAMMETRY FOR 3D DOCUMENTATION AND VISUALIZATION OF HISTORICAL HERITAGE

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ABSTRACT

In this paper, a scientifically based methodology is being developed for the application of an integrated approach combining terrestrial and UAV photogrammetry. The practical part refers to a digital spatial reconstruction of a Roman stone arch bridge in the village of Bogomila, Veles, which is a significant component of the historical heritage of Macedonia. The process of applying terrestrial and drone photogrammetry for 3D documentation and visualization of historical-cultural heritage involves capturing, processing, and analyzing spatial data in order to create precise representations of these objects and their surrounding environments. These techniques are essential for the creation of digital twins, which provide a virtual replica of objects and places of historical and cultural significance. Additionally, they provide immersive experiences that enhance public engagement and appreciation of cultural heritage.

Keywords: photogrammetry, cultural heritage, digital twins, 3D cartography, visualization, 3D modeling

INTRODUCTION

The intensive progress of digital photogrammetry opens incredible possibilities for mass acquisition of field data, with the aim of creating photorealistic spatial models. In this context, it is important to emphasize that digital photogrammetry plays a significant role in solving the challenges associated with 3D modeling of significant objects geometry. (Granshaw, 2019) This ensures documentation that not only protects cultural-historical heritage but also enables numerous users to explore and experience it through a digital platform, regardless of time and location. The combination of terrestrial and unmanned photogrammetry represents an advanced approach that further improves the visual characteristics of the final model. (Olson R., 2020) These models serve as digital replicas, preserving the object's form and details in a virtual environment. By generating accurate digital records, photogrammetry helps document the condition of objects, a fundamental aspect for conservation and restoration endeavors. In case of damage or loss, these models can also serve as reference base for reconstruction. Institutions can use these digital replicas to implement security measures and monitor changes in the condition of artifacts over time. Photorealistic models offer valuable insights into the structural integrity and vulnerabilities of cultural objects. Conservationists can leverage these models to evaluate risks such as degradation, structural instability, or environmental threats. This paper

aims to highlight the potentials of digital photogrammetry as a powerful tool for the promotion and protection of cultural heritage.

Study area

The ancient Roman bridge is located in the center of the village of Bogomila in the Azot region in the eastern part of the territory of the municipality of Čaška in the original catchment area of the Babuna river. It is placed in the northeast-southwest direction across the Babuna river, about 2 km from the railway station in Bogomila. The bridge belongs to the type of single-arch bridges and is classified as a significant cultural heritage site defined by the National Institution "Conservation Center" - Macedonia. The exact construction time of the bridge is not precisely determined. There is a belief among the people that the bridge dates back to the Roman period. It serves as a witness to the history of architectural development in our territory and as such is an important element for study in the context of scientific research on the development and peculiarities of construction in Macedonia. (NU National Conservation Center, 2020)



Figure 1. Map of Europe with marked N. Macedonia.
Source: (https://commons.wikimedia.org/wiki/File:Macedonia_in_Europe.svg)

Location of the bridge with geographic coordinates:

- North (N) = 41° 35’ 43’’
- East (E) = 21° 28’ 40’’
- Altitude (H) = 493 meters above sea level.

During its existence, the bridge underwent numerous interventions aimed at preserving its stability. However, with the construction of the new bridge (2019-2020), unfortunately, besides altering the surroundings, the appearance of the terrain has also changed, leading to

interventions being carried out up to the front walls of the bridge. (NU National Conservation Center, 2020)



Figure 2. The oldest found image of the bridge.
Source: (National Conservation Center – Skopje [9])

The protection and conservation of this heritage not only enriches us with historical sites and traditions, but also passes on important lessons and experiences to next generations. Therefore, investing in the protection of cultural heritage is a long-term investment in our future, preserving the richness of our culture for future generations. (Franchi E., 2017)

Purpose of research

The research aims to generate a visually rich, but also technically precise 3D model, which will serve for the documentation and conservation of the cultural-historical heritage. Additionally, the research focuses on integrating unmanned aerial and terrestrial photogrammetry, for digital spatial reconstruction of the geometry of an ancient Roman bridge in the village of Bogomila, Veles, which is a significant part of the historical heritage of Macedonia.

Methods of research

The implementation of the practical part of the work includes field activities that include the use of various modern measurement technologies, such as the DJI Phantom 4 Pro drone, the triple photo camera from the iPhone 14 Pro smartphone, the Leica Viva TS11 total station and the Leica Viva CS10 GPS. The drone is used to capture high-resolution aerial imagery of the bridge with flight paths strategically planned to achieve thorough coverage from various angles and elevations with support of Drone Deploy platform. Meanwhile, the smartphone camera is employed for capturing detailed close-up images of specific architectural features of the bridge, providing additional visual data for analysis. The GPS device and total station contribute to precise positioning and georeferencing of both the imagery and survey data, guaranteeing spatial accuracy throughout the reconstruction process.

Geodetic measurement technology cannot be functional, without support from appropriate software packages for photogrammetric processing and point cloud processing. Several applications and software tools such as Agisoft Metashape, Cloud Compare were used during the

processing of the acquired field data. The used field data for processing is discussed in the next chapter.

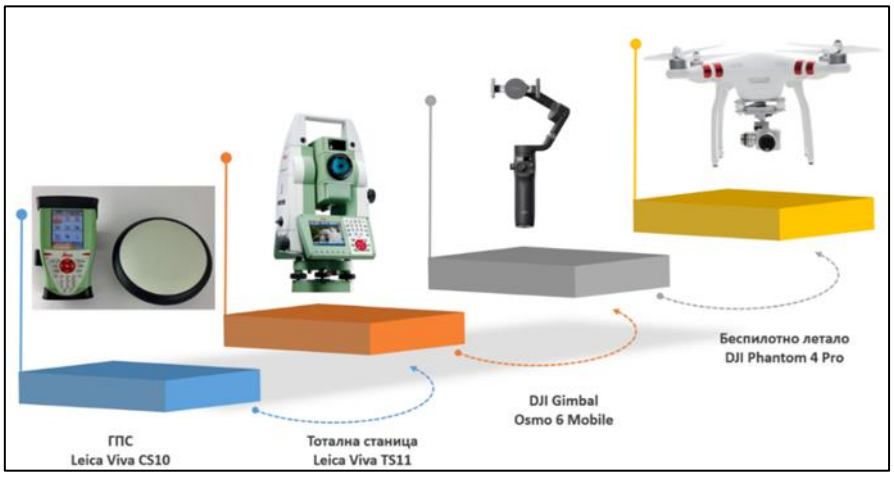

Figure 3. Geodetic measurement technology

GEODETIC MEASUREMENTS

Obtaining comprehensive and precise data, as well as creating a precise digital model with high-resolution detail, presents a challenge for every geodetic professional. It requires the use of a combination of terrestrial and aerial surveying methods, often utilizing advanced technologies like LiDAR or photogrammetry. (Lynn, 2021)
Geodetic measurements include the following activities:

- GNSS measurements for establishing a reference base for the application of photogrammetric and terrestrial surveying methods;
- Terrestrial measurements with a reflector less total station for the markers that are positioned laterally across the surface of the entire bridge, including its arched section, to enhance uniformity;
- Photogrammetric acquisition using an unmanned aerial vehicle (drone);
- Terrestrial photogrammetry acquisition utilizing triple smartphone camera.

Field data

The reference base consists of a total of 13 orientation points, including 5 markers placed on the roadway of the bridge itself, specifically on the base and surrounding areas, while the remaining 8 markers are positioned laterally across the entire surface of the bridge (Fig. 4). These markers are identified with standardized symbols for photogrammetric measurements, and their coordinates are determined using the Leica Viva CS10 GPS device in GNSS RTK method with support from the MAKPOS system, achieving an accuracy of ±2 cm. The coordinates of the markers positioned laterally across the entire side surface of the bridge, as well as inside the bridge's arch, were obtained through laser measurements using the Leica TS11 total station.



Figure 4. Orientation points used in field measurements.

After capturing the orientation points with the GNSS device and the total station, the aerial photogrammetric survey is conducted using the DJI Phantom 4 Pro drone. The flight is supported by the Drone Deploy mobile application. From the conducted aerial survey at a flying altitude of 50 meters, 82 digital images were obtained with a ground resolution of 1.1 cm/pixel. The terrestrial photographs were captured using the triple camera of the iPhone 14 Pro smartphone, which was mounted on the handheld DJI Gimbal Osmo 6 tripod for stability during shooting, ensuring better visibility and satisfactory overlap between the images. A total of 100 images were taken, focused on the geometry of the bridge, which were then merged with other images during software processing.

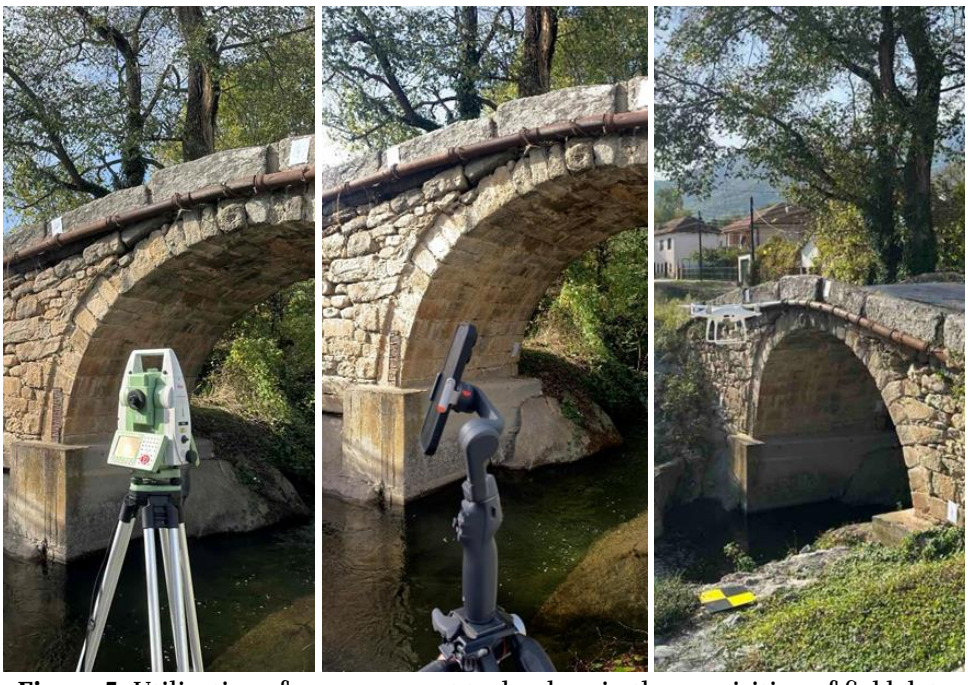

Figure 5. Utilization of measurement technology in the acquisition of field data

RESULTS AND DISCUSSION

Agisoft Metashape software is used to process aerial imagery from the drone and terrestrial images from the smartphone camera. The 3D model reconstruction process employed advanced software algorithms designed for close-range digital photogrammetry. In this process, the software analyzes the pixel information in the images, identifying common features or points between overlapping images, and uses this information to triangulate the position of these points in 3D space. By combining information from multiple images, the software can reconstruct the geometry and texture of the object or scene with high precision. (Milanov L., 2024)

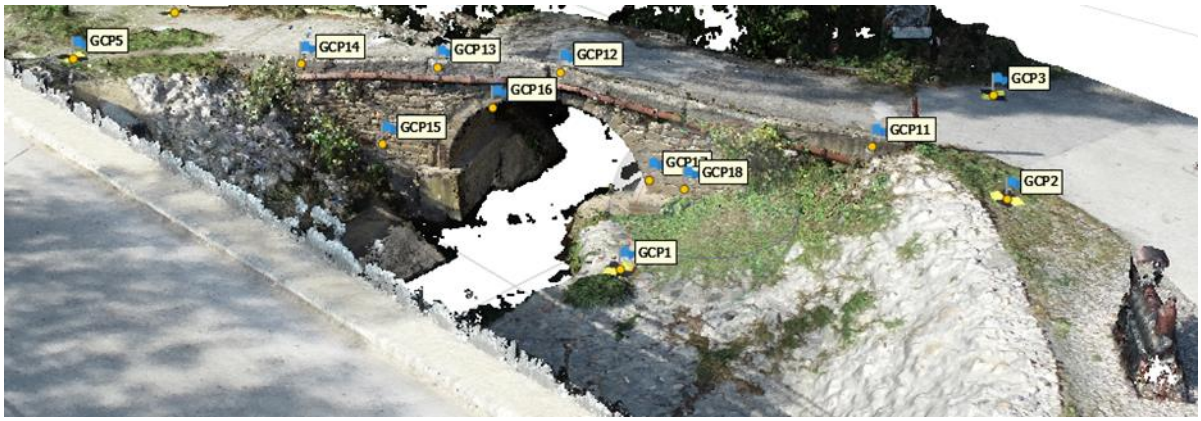

Figure 6. Graphical representation of the dense point cloud with marked positions of the control points

The dense point cloud consists of detailed 3D points, where each point represents an exact location in 3D space and contains surface geometry details. This dataset provides plenty of spatial information, allowing for advanced analysis, immersive visualization, and precise modelling. (Thomson C., 2019)

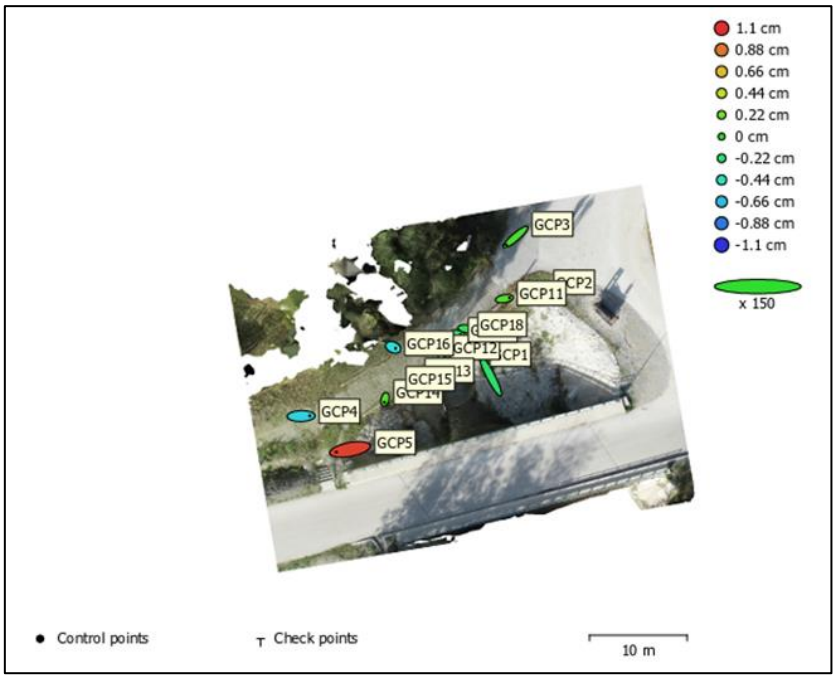

Figure 7. Ellipse of errors around the orientation points

According to the report that is generated after the photogrammetric processing in Agisoft Metashape software, we can determine the accuracy of the resulting point cloud, as well observe the parameters used in the image processing.

Photogrammetric products

Photogrammetric products encompass a range of outputs derived from photogrammetric techniques, including orthophotos, digital elevation models (DEMs), point clouds, and 3D models. (Agisoft LLC, 2019) These products serve diverse applications such as cartography, urban planning, environmental monitoring, and infrastructure development by providing accurate spatial information and detailed representations of terrain and objects.

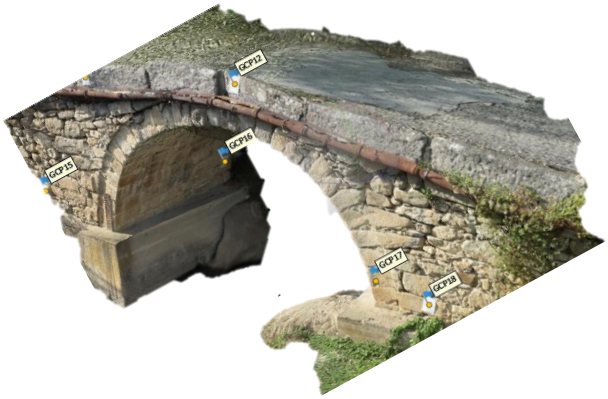

Figure 8. 3D model with generated texture.

The digital elevation model (DEM) is a computerized representation of the Earth's surface, showing terrain features and elevation. It's stored in a raster format, where each pixel represents a specific height, giving detailed insight into the landscape's topography. (Llames H. G., 2023)

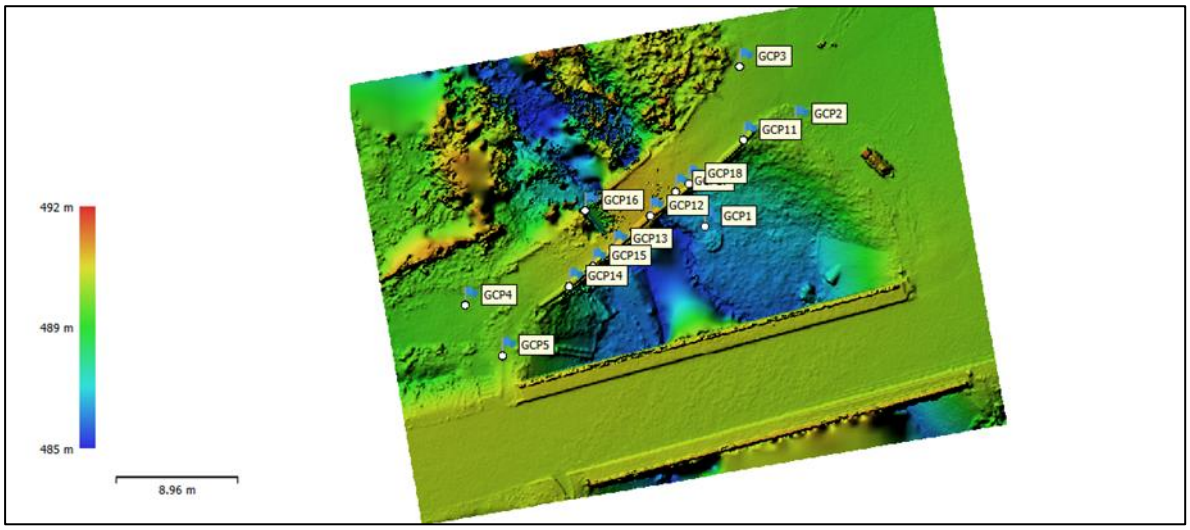

Figure 9. Digital elevation model of the site

Cloud Compare (open source) is used to process point clouds, integrating and analyzing data from various sources like laser scanning and photogrammetry. It visualizes and manipulates point cloud data to extract more information about the bridge's structure. Additionally, it offers many additional features, including comparison of two models. (CloudCompare, 2015)

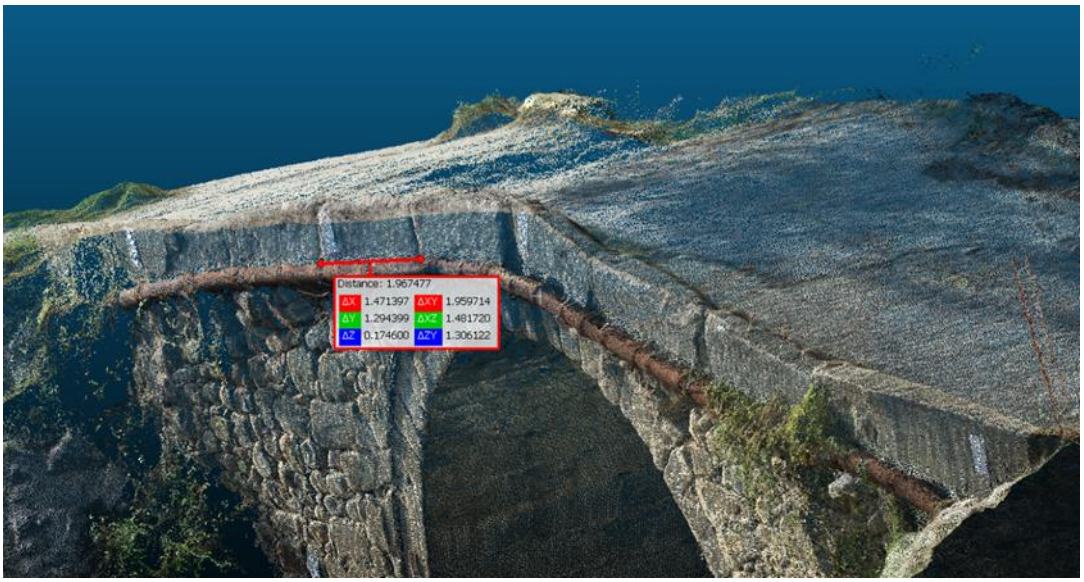

Figure 10. Measuring distance between points in the CloudCompare software.

As a practical control and confirmation of quality, distances between identical control points in the model are measured and compared with those calculated based on coordinates determined by classical methods. Extremely good values within a few centimeters are established. On the graphical representation, we can identify a difference of 5 cm in a distance of 9.24 meters.

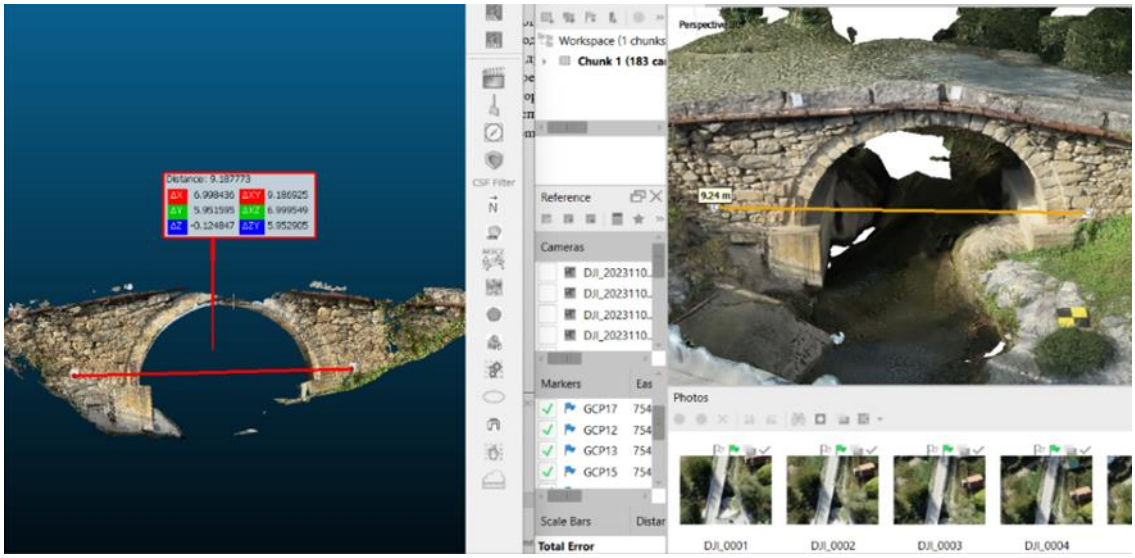

Figure 11. Graphic representation of the comparison of the same distances from two models.

The described methodology offers a robust approach to documenting and analyzing cultural heritage sites like the Roman bridge. Despite challenges in cost and expertise, the benefits

of comprehensive data collection, high-quality visualization, and versatile data analysis outweigh these limitations. Similar studies, like that of Pepe, et al. (2020), using both terrestrial and UAV photogrammetric surveys, validate the effectiveness of these methods in heritage preservation and research. As technology continues to advance and resources become more accessible, these methodologies are likely to see further improvements and expanded application in the future.

CONCLUSION

The digital reconstruction of historical heritage objects involves a multidisciplinary approach that uses different technologies and methods for the virtual representation and revival of historical objects. The investigations in this paper on 3D documentation, including terrestrial and UAV photogrammetry, combined with classical measurement methods and appropriate software packages, are performed in order to highlight the advantages and possibilities, but also the disadvantages of this approach for data acquisition and visualization, especially when dealing with objects categorized as cultural heritage. Objects of historical cultural significance are an important part of the national heritage and are subject to the risk of destruction due to various factors such as age, the effects of weather conditions, human activities, and more. Through documentation and conservation projects by creating detailed photorealistic 3D models, their value and significance is preserved for the future. These models create a virtual archive that can be used for a variety of purposes. In the specific case of implementation, of a complex combination of technologies results in the creation of a detailed and high-quality spatial model. This model significantly contributes to the documentation and conservation of the historical heritage, in this case, the ancient Roman Bridge in the village of Bogomila. This is critically important for ensuring its long-term protection and accessibility for future generations.

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