การอนุรักษ์ในรูปแบบดิจิทัลของแหล่งซากดึกดำบรรพ์รอยตีนไดโนเสาร์แห่งแรกของประเทศไทยโดยใช้เทคนิคโฟโทแกรมเมทรีสำหรับแบบจำลอง 3 มิติ

Digital conservation of the first dinosaur tracksite of Thailand using photogrammetry for 3D modeling

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บทคัดย่อ

ซากดึกดำบรรพ์รอยตีนไดโนเสาร์ที่มีการบันทึกไว้ครั้งแรกในเอเชียตะวันออกเฉียงใต้ถูกค้นพบในปี พ.ศ. 2527 รอยดังกล่าวถูกพบอยู่บริเวณผาสมเด็จในเขตรักษาพันธุ์สัตว์ป่าภูหลวง จังหวัดเลย ภาคตะวันออกเฉียงเหนือของประเทศไทย บริเวณดังกล่าวมีลักษณะเป็นแผ่นหินทรายจากหมวดหินภูพานของยุคครีเทเชียสตอนต้น และเป็นรอยตีนที่พบเพียงแหล่งเดียวจากยุคนี้ อย่างไรก็ตามบริเวณเส้นทางภูหลวงมีความเสี่ยงที่จะเสื่อมสภาพตามกาลเวลาเนื่องจากสภาพอากาศ สัตว์ และกิจกรรมของมนุษย์ การศึกษานี้มีวัตถุประสงค์เพื่อติดตามแผนการอนุรักษ์ในรูปแบบดิจิทัลโดยใช้แบบจำลอง 3 มิติที่สร้างจากเทคนิคโฟโตแกรมเมทรี แบบจำลองสามมิติที่ได้จากวิธีนี้สามารถเก็บข้อมูลพื้นผิว สี และแสดงผลลักษณะของตัวอย่างในช่วงเวลานั้นได้ให้ผลที่ดีกว่าและง่ายต่อการนำมาใช้งานเมื่อเทียบกับวิธีการเดิม เช่น การทำพิมพ์รอยตีน แบบจำลองเหล่านี้ให้ข้อมูลรายละเอียดเพื่อการอนุรักษ์และส่งเสริมการสื่อสาร การทำงานร่วมกันทางวิทยาศาสตร์ การใช้โฟโตแกรมเมทรีช่วยให้การผลิตข้อมูลรวดเร็วและคุ้มค่า เป็นประโยชน์ต่อผู้เชี่ยวชาญและสาธารณชนในการอนุรักษ์และเผยแพร่ความรู้

คำสำคัญ: หมวดหินภูพาน, กลุ่มหินโคราช, ยุคครีเทเชียสตอนต้น, แบบจำลองสามมิติ, รอยตีนไดโนเสาร์

Abstract

The first documented dinosaur footprints in Southeast Asia were discovered in 1984. The footprint site is located on the Somdet cliff overlying Phu Luang hill in the Phu Luang Wildlife Sanctuary, Loei Province, Northeastern Thailand. The tracksite is imprinted on a sandstone bed of the Phu Phan Formation, Lower Cretaceous. It is the only footprint track discovered from this stage in Thailand. However, the Phu Luang tracksite is at risk of deterioration due to climate, animal, and human activities. This study aims to monitor a digital conservation plan for this tracksite using 3D models generated through digital photogrammetry. This method’s 3D model output can capture texture and color, and can represent the properties of the specimen at the time. When compared to older processes such as cast and mold footprint, it produces better results and is easier to use. These models provide informative data in detail for conservation and enhance scientific communication and collaboration. By adopting photogrammetry, data production becomes rapid and cost-effective, benefiting specialists and the public for conservation and knowledge dissemination.

Keywords: Phu Phan formation, Korat group, early cretaceous, 3D model, dinosaur footprints

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Introduction

The discovery of dinosaur footprints in Southeast Asia started in 1884. Thailand has a rich history of dinosaur discoveries, including several dinosaur tracksites found in different localities, and these remarkable findings were among the first documented fossil vertebrate footprints in Southeast Asia. (Buffetaut *et al*. 1985a). This first dinosaur tracksite was reported to have fifteen footprints embedded on a sandstone bed of the Phu Phan Formation, located at the Somdet cliff in the Phu Luang Wildlife Sanctuary of Loei Province (Lat 17.293520177762456N, Long 101.52982315394472E), northeastern Thailand (Figure 1).

The footprint maker was attributed to a large theropod with a footprint length of approximately 35 cm. The Phu Phan Formation is part of the Khorat Group and dates back to the Early Cretaceous period (Buffetaut *et al*. 1985b; Le Loeuff *et al*., 2005, 2006; Lockley *et al*. 2002, 2006;).

Forty years later, it is worth noting this area is the part of the nature trail and viewpoint of Somdet cliff, and that the Phu Luang tracksite faces significant risks of deterioration. Factors such as the region's humid subtropical climate, wild animals, and human activities threaten the preservation of these prehistoric footprints. Without proper conservation efforts, there is a potential for erosion and degradation of the footprints over time. (Figure 2).

To address these risks and protect the valuable dinosaur footprints, researchers propose a conservation plan (Site Monitoring and Maintenance, Visitor Education, Scientific Research, Documentation and Record-Keeping, Community Engagement, Emergency Response Plan, and Collaboration) based on a digital plan. This plan uses 3D models generated through the digital photogrammetry technique (Albertz, 2007; Mallison and Wings, 2014), providing detailed and accurate morphological information of the tracksite (e.g., Lyons *et al*., 2000; Falkingham, 2012; Cunningham, 2014; Petti *et al*., 2018; Martinez *et al*., 2020). These digital models offer promising avenues for virtual documentation, exhibition, and preservation of the dinosaur tracks, which are susceptible to weathering.

Materials and Methods

Photogrammetry

A field survey was conducted to generate digital surface models of the dinosaur tracksite using photogrammetry. A Canon PowerShot G7 X Mark II digital compact camera with a resolution of 20.1 megapixels was utilized for this purpose. The camera's focal length (35 mm film equivalent) could be adjusted from 8.8 to 36.8 mm (24-100 mm). Data acquisition involved capturing 395 images divided into photosets from various viewpoints with overlapping patterns of 60 to 80 percentage. 21 calibration markers (Physical target point print-out from Metashape) were placed near the footprints to scale the 3D models. The images were taken manually while walking around the tracksite, with each photo captured at a distance equivalent to one walking step (0.5 to 1 m). The photography session took place between 1 p.m. and 3 p.m. in January 2022 to ensure adequate sunlight. Camera settings included dimensions of 4864 x 3648, 180 dpi x 180 dpi resolution, F/11 aperture, ISO speed of 125, focal length of 9 mm, white balance set to auto, no flash, and the export format set to JPG.

Data processing

Data processing was performed on a PC with an Intel® Core(TM) i7-6700 processor operating at 3.40 GHz, 64.0 GB RAM, and Windows 10 as the operating system. The software used for creating 3D models was Agisoft Metashape Professional Edition Version 1.7.1, following the procedure established by Mallison & Wings (2014); Falkingham *et al*. (2018) and Lallensack *et al*. (2022). This software enables the derivation of three-dimensional models, point clouds, digital elevation models (DEMs), and their integration with GIS products. The data analysis and derivation process in this study consisted of the following steps: 1) adding photos, 2) aligning photos, 3) creating mesh and texture, 4) generating DEM, and 5) exporting the model.

Twenty-one markers were set on the tracksite to scale and orientate the 3D model accurately. These markers were placed on the sandstone bed. The accuracy of the scale was set at 0.01 m center radial in the black circle. Additionally, these markers were placed on the ground level at similar altitudes to orient the surface perpendicularly to the Z axis and produce a Digital Elevation Model (DEM). These ground-level markers were assigned to position the entire model perpendicular to the surface, use the Z coordinate value of 0.

Results

The field survey capturing 395 images (Figure 3), covered an area of about 13.75 m². The images were interpolated and processed with high-quality accuracy to generate a sparse point cloud consisting of at least 128,000 points. The processing time for this step was approximately 5 hours. A dense point cloud was created from the sparse point cloud, comprising 3.4 million points. Subsequently, a mesh with at least 1.8 million faces was generated, and a texture was applied to the 3D models. The 3D models were exported as OBJ files, while the texture and contour lines were saved as JPEG files. Additionally, the Digital Elevation Model (DEM) was exported as a TIFF file. Using photogrammetric techniques resulted in the acquisition of high-resolution digital data, encompassing digital surface models and ground resolutions. A summary of these outcomes is presented in Table 1.

Table 1 Technical parameters of a 3D model on the Phu Luang tracksite

Method	Photogrammetry
Software	Agisoft Metashape
Number of Images	395.
Height from the ground (m)	1
Collecting duration (min)	30
Processing time	5 hrs.
Area (sq m)	13.75
DEM resolution (pixel)	9,038 x 15,447

The application of photogrammetry in ichnological studies is becoming more common, as demonstrated by the Phu Luang dinosaur tracksite surveys. Photogrammetry has enabled the production of high-resolution images, allowing for rapid data acquisition for each investigated track. The images can be thoroughly examined using software that allows users to tilt and zoom into the 3D model, facilitating track observation, analysis, and measurements. This method eliminates errors caused by original atmospheric and lighting conditions, as users can adjust and orient lighting specifically for each track. The photogrammetry provides an opportunity to study footprints with high accuracy and ideal lighting conditions, surpassing the limitations of field studies.

Discussion

In the case of the Phu Luang tracksite (Figure 4), the 3D model shows all detail of the 15 tridactyl large-sized tracks. The 3D model, similar to the sketch shown in Figure 4, reveals all the intricate details. Within the model, even subtle variations in morphology become evident due to factors such as overlapping impressions, individual foot structure differences, and varying degrees of weathering. Additionally, some areas, such as points a and b, within the 3D model exhibit footprints, even though they have not been explicitly mentioned before. This approach not only provides data but also unveils textures and details that might be challenging to discern with the naked eye. A prime example can be seen in locations a and b in Figure 4, where what appears to be dinosaur tracks become more evident upon closer inspection. Photogrammetry has proven ideal for capturing a detailed photographic footprint area, creating a comprehensive map and georeferenced visualization of the dinosaur tracks on the ground. The 3D models derived from point cloud processing accurately reproduce the trackways, enabling precise measurements. The 3D models provide detailed representations of the trackways; the models can be examined closely, zoom in, rotate, and tilt for different perspectives, enabling precise measurements of the footprints' length, width, depth, and orientation (Figure 5). The 3D model exhibits an impressive level of detail that is on par with the photographs. The key distinction lies in the 3D model's versatility — it can be rotated, adjusted, and zoomed in or out to provide different perspectives. Moreover, owing to the image resolution utilized during its generation, the solid model allows for the examination of surface details without the influence of lighting and shadow artifacts.

This non-invasive approach allows accurate data collection without risking damage to the fragile fossils, ensuring repeatability for consistent scientific research and facilitating comparisons between studies. Photogrammetry enables the generation of various products, including 3D models and videos, which researchers can use for remote inspections of the site and conservation and dissemination purposes.

Photogrammetry offers reliable and high-resolution images, which are portable, have reduced costs and faster execution. The long-term conservation of paleontological remains a topic of debate, and despite various attempts to document and restore dinosaur tracksites, the management and conservation of these sites continue to present challenges.

Replica methods: Digital vs Manual

In the paleontological field, replica processes for dinosaur footprints and other fossils are frequently used. When choosing a replication method, it is necessary to consider the intended use of the replicas, as well as the available resources, for studying and displaying fossils while preserving the original specimens. Each method has advantages and disadvantages, and the choice is typically influenced by the specific requirements of the project. In this study, the efficacy of photogrammetry and silicone mold techniques for replicating dinosaur footprint specimens was assessed, as detailed in Table 2 (Kozu, 2017).

Table 2 The comparison of Photogrammetry and Silicone Mold for Dinosaur Footprint

Method	Photogrammetry	Silicone mold
Type	Digital	Physical
Procedure time	1 hr.	72 hrs.
Field staff	1	2
Invasive	No	Yes
Damage	No	Yes
Portable	Yes	No
Usability	Easy	Hard

Photogrammetry stands out for its digital preservation and interaction with other technologies, as well as its non-invasive precision, distant data collecting capabilities, and adaptation to varied surfaces. Potential disadvantages include reliance on lighting conditions and a learning curve for equipment use. The silicone mold, provides tangible copies suited for hands-on education and museum displays, but it is an invasive process, labor-intensive, and confined to physical replicas. The intended purpose, preservation issues, and financial considerations are all factors to consider when deciding between approaches. As technology advances, an intelligent choice of replication methods will influence the future of paleontological study and teaching by balancing precision, accessibility, and affordability.

When comparing 3D scanning for dinosaur footprint 3D modeling, photogrammetry emerges as a highly advantageous method. (Jansa *et al.*, 2004) Its accessibility, cost-effectiveness, and minimal equipment requirements make it an appealing option for researchers. Photogrammetry's versatility in handling various subject sizes, large-scale capabilities, and adaptability to fieldwork contribute to its broad applicability in paleontology. The user-friendly software, community support, and educational value further enhance its standing. While both methods have strengths, the numerous pros of photogrammetry, including its non-invasiveness and low impact on specimens, position it as a preferred choice for creating accurate and detailed 3D models of dinosaur footprints, fostering a balance between precision, accessibility, and practicality in the field of paleontological. (e.g., Cunningham *et al.*, 2014; Chatzi *et al.*, 2017).

Conservation plan

The long-term protection and preservation plan of these paleontological sites, the conservation strategy for the dinosaur footprints at the Phu Luang tracksite is essential. The main methods that a enable a conservation strategy to protect dinosaur footprints are as follows.

1) Site Monitoring and Maintenance consistent site monitoring is necessary to detect any risks or modifications. Cleaning, fixing, and stabilizing the imprints are all examples of maintenance procedures that can be used to stop erosion, weathering, or other types of damage.

2) Visitor Education. It is essential to inform visitors of the significance of the place and its

preservation. Visitor centers, narrated tours, and interpretive signage can all aid in promoting awareness and appropriate behavior.

3) Scientific Research. Scientific study can be encouraged at the site in order to better understand the footprints while complying with conservation guidelines. To limit their impact, researchers should adhere to tight guidelines.

4) Documentation and Record-Keeping. Meticulous records should be kept, photographs, and 3D models of the footprints to document their current state. This provides as a starting point for tracking changes throughout time.

5) Community Engagement. Involve local people in conservation efforts, as they frequently play an important role in conserving and valuing cultural heritage assets.

6) Emergency Response Plan. Develop an emergency response plan to deal with unexpected risks such as natural disasters, vandalism, or illegal excavation. This plan should include rapid protection and recovery techniques.

7) Collaboration. Collaborate with paleontologists, conservationists, government agencies, and local stakeholders to ensure that the footprints are preserved in a coordinated manner.

A successful conservation strategy for dinosaur footprints must take a holistic approach that combines safeguards, awareness-raising, study, and continual observation. We can assure the survival of these priceless scientific and cultural riches for future generations to study and admire by putting these plans into practice.

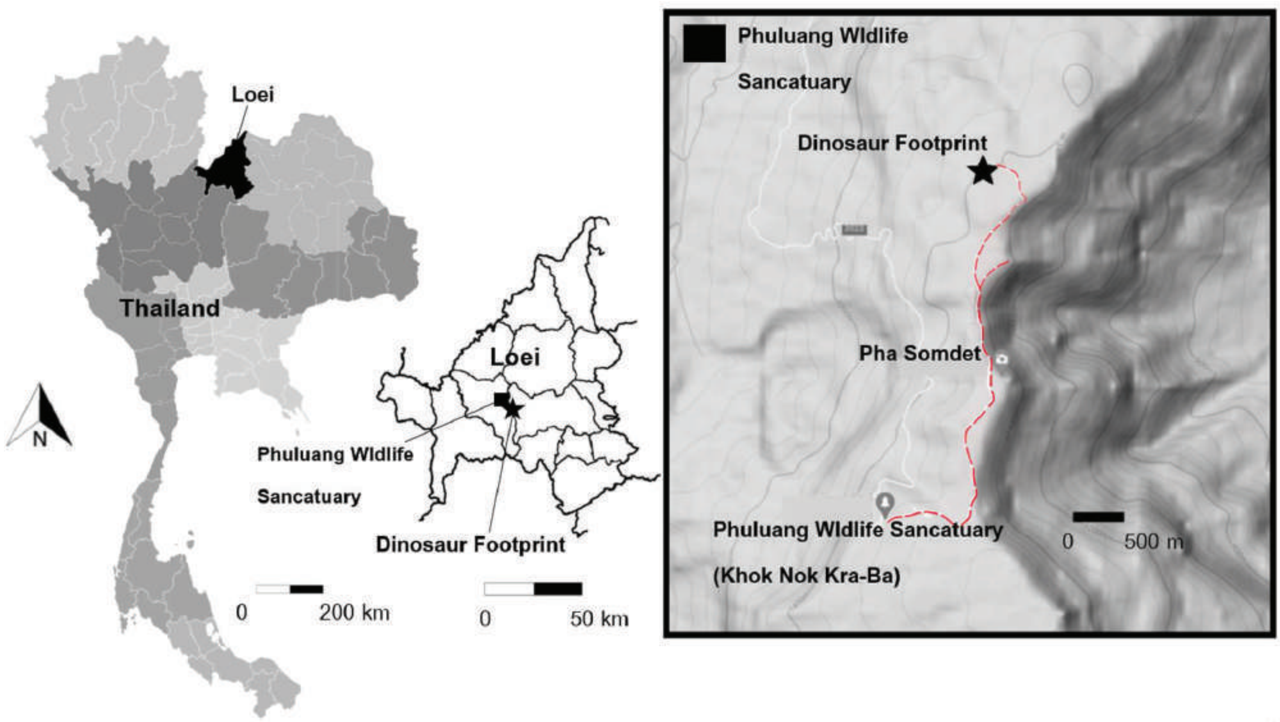

Figure 1 Locality map showing the Phu Luang tracksite in The Wildlife Sanctuary, Loei Province, Northeastern Thailand. Image obtained using data from Google Earth Pro.

Figure 2 a. The Phu Luang tracksite on the sandstone bed of the Phu Phan Formation by Kozu (2017). b. large theropod footprint

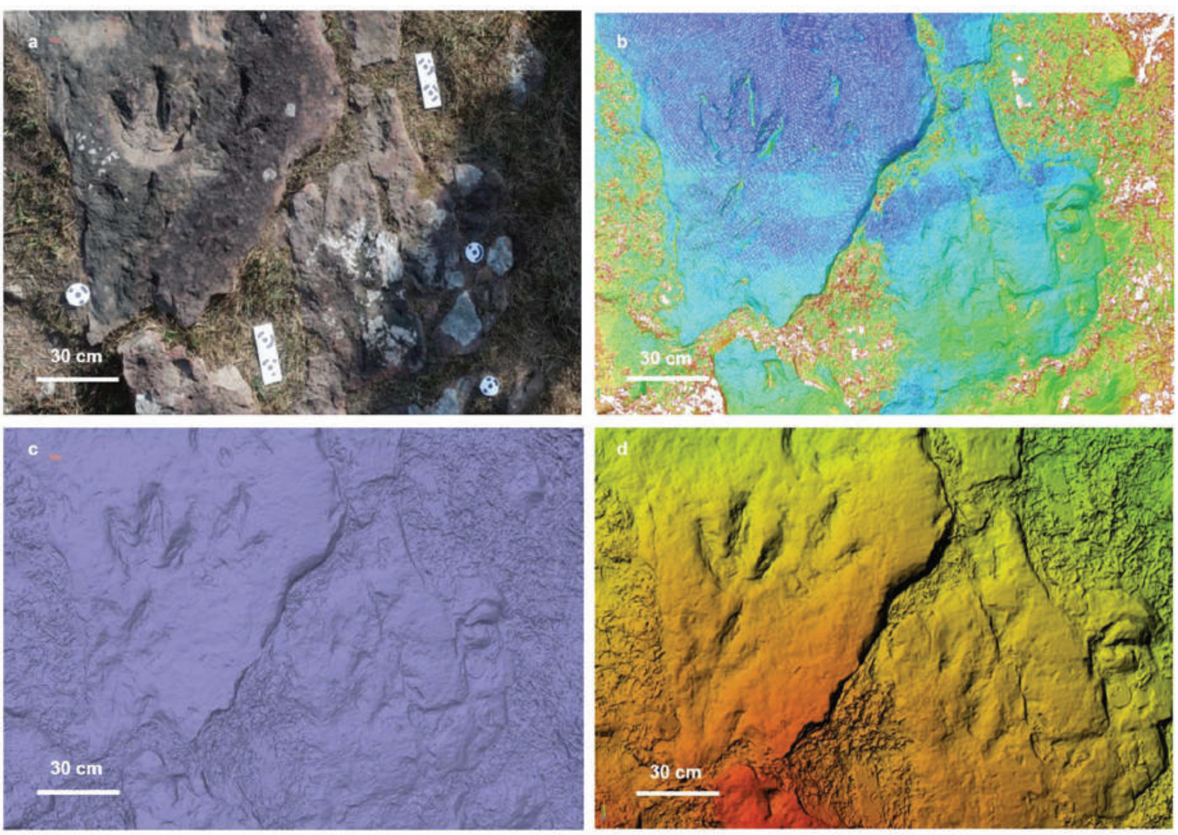

Figure 3 Comparison of the results obtained on a large area. a, photo with drawing track; b, Point cloud; c, Mesh solid model; d, DEM. All photos with a 30 cm scale.

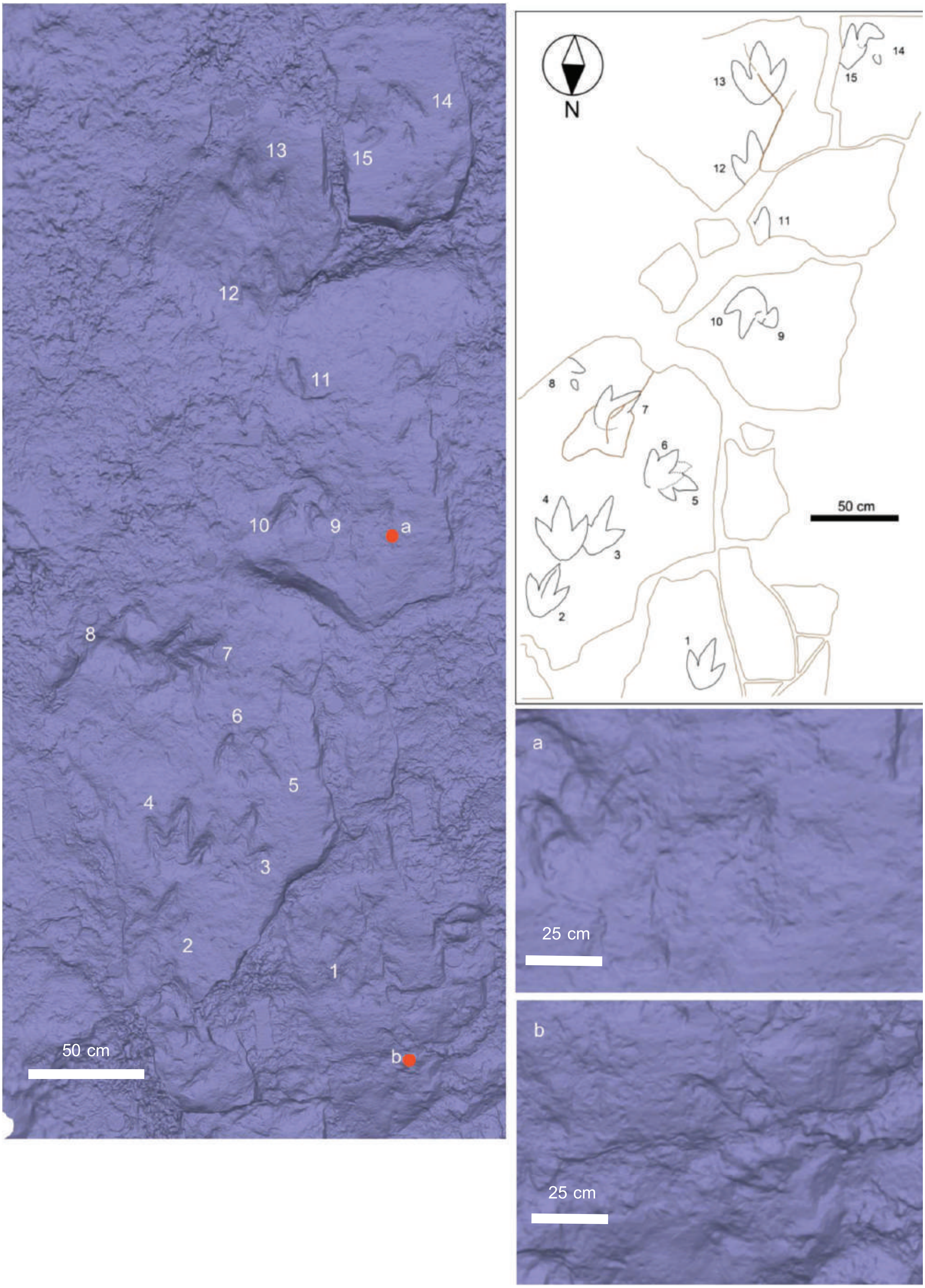

Figure 4 3D Model vs Sketch of the tracks at the site Phu Luang modified by Kozu (2017).

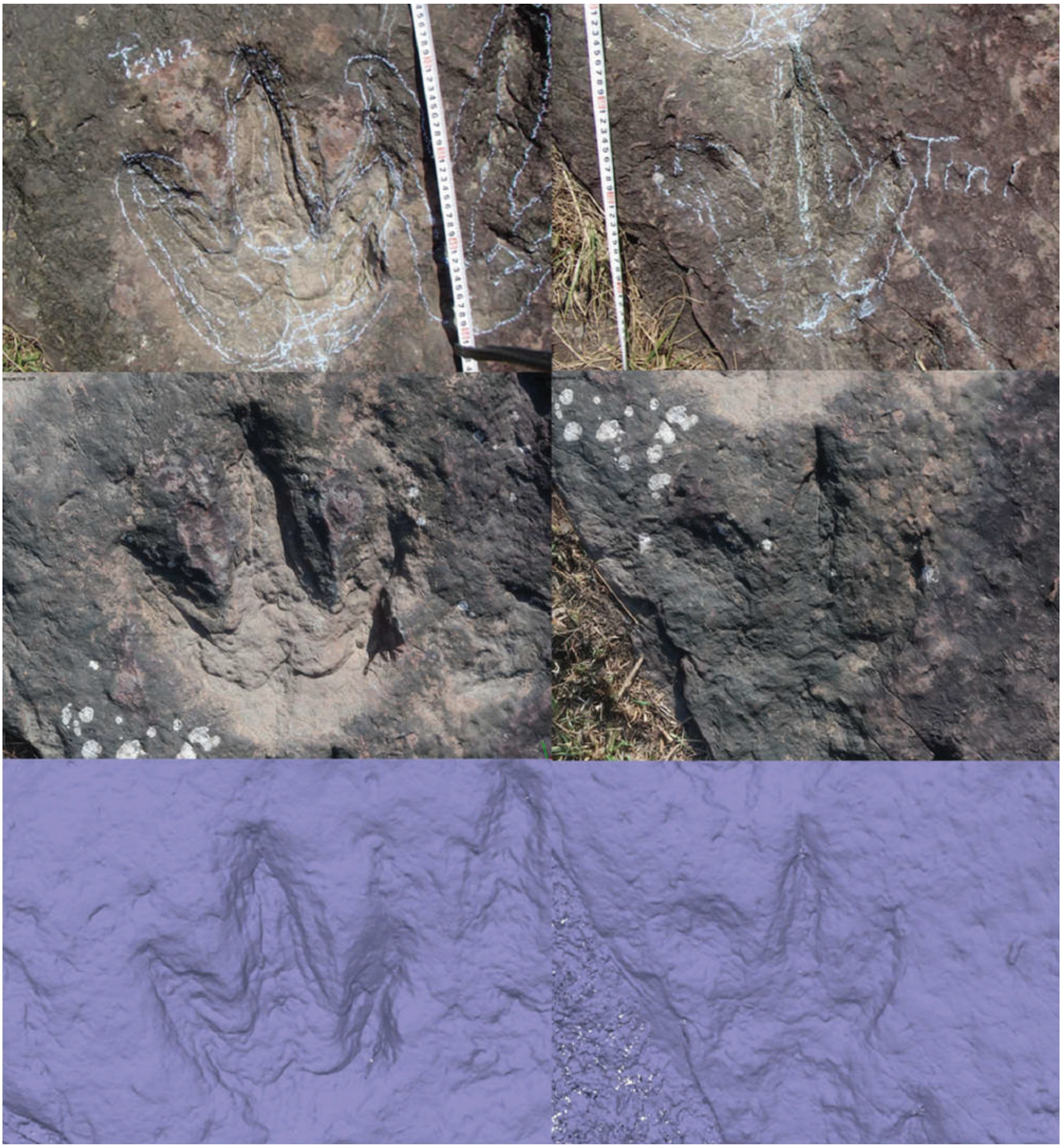

Figure 5 Comparison of the 3D model and photos Kozu (2017). Top) photo of a footprint No. 4 (left) and No. 2 (right). Middle) 3D models of footprints with texture bottom) 3D models solid without texture.

Conclusion

Photogrammetry not only produces high-quality data for monitoring, but it also shows textures and complex features that the naked eye may miss. Notably, what appears to be dinosaur tracks becomes much more obvious with closer inspection. Field data and images were used to map dinosaur tracksites. The current addition gives a new and effective tool for revealing dinosaur footprints on trampled surfaces. We report the results of photogrammetry done at the Phu Luang tracksite. The purpose of this work was to evaluate the resolution and trustworthiness of the large-scale models beneficial for creating a detailed and georeferenced map as well as a visual contextualization of the ichnosite. This level of detail and precision enhances our ability to understand these footprints, shedding new light on the behaviors and movements of dinosaurs. These techniques provide valuable tools for scientific research and contribute to the preservation, exhibition, and communication of tetrapod tracks. By implementing the proposed conservation measures, we can ensure the protection and appreciation of the Phu Luang track site for future generations. This site represents a significant part of the rich dinosaur heritage in the region and holds scientific, educational, and touristic value. It is important to note that the proposed photogrammetry approach does not replace traditional analytical methods such as field mapping, tracing on acetate overlays, and casting. Instead, it complements and improves these methods, providing the researcher with consistent, cost-effective, and rapid methodologies for studying tracksites at both the track and site scale.

Moreover, photogrammetry can be utilized for paleontological knowledge of tracksites and fossils for virtual sites on the web, exhibitions, and outdoor panels.

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