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CREATING 3D MODELS AS DIGITAL TWINS OF OBJECTS OF THE CULTURAL AND HISTORICAL HERITAGE OF KRASNODAR KRAI

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Evgeny Boyko
Institute of Geography, Geology, Tourism and Service, Kuban State University, Krasnodar, Russia. Orcid id: http://orcid.org/0000-0001-8105-7989 E-mail: boykoes@yandex.ru

Tatiana Volkova
Institute of Geography, Geology, Tourism and Service, Kuban State University, Krasnodar, Russia. Orcid id: http://orcid.org/0000-0002-2054-0683 E-mail mist-next4@inbox.ru

Maksim Kucher
Institute of Geography, Geology, Tourism and Service Kuban State University, Russia. Orcid id: http://orcid.org/0000-0003-2464-8066 E-mail: Maxkucher93@gmail.com

Vera Minenkova
Institute of Geography, Geology, Tourism and Service Kuban State University, Krasnodar, Russia. Orcid id: http://orcid.org/0000-0003-4184-2522 Email: minenkova@inbox.ru

Dmitry Komarov
Institute of Geography, Geology, Tourism and Service Kuban State University, Krasnodar, Russia. Orcid id: http://orcid.org/0009-0001-4181-9755 E-mail: dakomarov@inbox.ru

Natalia Pikalova
Institute of Geography, Geology, Tourism and Service Kuban State University, Krasnodar, Russia. Orcid id: http://orcid.org/0000-0003-2438-6457 E-mail: pna678@mail.ru

ABSTRACT

Objective: The study aims to test a new methodology for creating digital models (digital twins) of cultural and historical heritage (CHH) objects in Krasnodar Krai, Russia. The goal is to popularize these heritage objects by making them accessible through digital platforms, attracting attention to the region's history and geography.

Methods: The methodology involves taking stereo photographs of heritage objects with a ground camera, performing geodetic measurements, and using specialized software (Agisoft Metashape) to create 3D models. The process includes constructing a dense point cloud, creating a polygonal model, texturing, and setting the coordinate system for accurate georeferencing.

Results: The study demonstrates that this method of creating digital twins is efficient, cost-effective, and allows the creation of high-precision 3D models of cultural heritage objects. The project produced 3D models of selected landmarks, such as the Church of Iveron Icon of the Mother of God and the monument-arch for the 50th anniversary of Psekup mineral waters. These models are integrated into a geoportal for public access.

Conclusion: This project will enable wider public access to cultural heritage sites, promoting the region's history and geography. The tested methodology is scalable and cost-effective, providing a solid foundation for future digital twin projects in the region.

Keywords: Digital twin, 3D modeling, Cultural heritage, Krasnodar Krai, Geoinformation system.

CRIAÇÃO DE MODELOS 3D COMO GÊMEOS DIGITAIS DE OBJETOS DO PATRIMÔNIO CULTURAL E HISTÓRICO DO KRAI DE KRASNODAR

RESUMO

Objetivo: O estudo visa testar uma nova metodologia para criar modelos digitais (gêmeos digitais) de objetos do patrimônio cultural e histórico (PCH) no Krai de Krasnodar, Rússia. O objetivo é popularizar esses patrimônios tornando-os acessíveis por meio de plataformas digitais, atraindo a atenção para a história e geografia da região.

Métodos: A metodologia envolve a captação de fotografias estereoscópicas dos objetos de patrimônio com uma câmera terrestre, realizando medições geodésicas, e utilizando software especializado (Agisoft Metashape) para criar modelos 3D. O processo inclui a construção de uma nuvem de pontos densa, criação de um modelo poligonal, texturização e definição do sistema de coordenadas para georreferenciamento preciso.

Resultados: O estudo demonstra que esse método de criação de gêmeos digitais é eficiente, econômico e permite a criação de modelos 3D de alta precisão de objetos do patrimônio cultural. O projeto produziu modelos 3D de marcos selecionados, como a Igreja do Ícone de Iveron da Mãe de Deus e o arco-monumento para o 50º aniversário das águas minerais de Psekup. Esses modelos foram integrados a um geoportal para acesso público.

Conclusão: Este projeto permitirá o acesso público mais amplo aos sítios de patrimônio cultural, promovendo a história e geografia da região. A metodologia testada é escalável e econômica, fornecendo uma base sólida para futuros projetos de gêmeos digitais na região.

Palavras-chave: Gêmeo digital, Modelagem 3D, Patrimônio cultural, Krai de Krasnodar, Sistema de geoinformação

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INTRODUCTION

Work on the creation of digital twins of spatial objects has been underway worldwide since the time of the widespread introduction of computer technologies and the development of appropriate software and remote sensing methods (Osintseva et al. 2023; Laiskhanov et al. 2021). Both small companies and educational institutions and major global corporations such as Microsoft, Apple, etc. are working in this direction (Gladilina et al. 2022). In Russia, digitalization is one of the priority areas of modern economic and social development (Kirillova et al. 2021; Fedchenko et al. 2023). The development of electronic resources and databases (Grudtsina et al. 2022), including geodata (Volkova et al. 2023), is an important task that allows a fundamentally new approach to inventory, monitoring (Bochkareva et al. 2023), protection, and management (Kiseleva et al. 2023), as well as the popularization of cultural and historical heritage (CHH) objects (Sergeeva et al. 2023; Balova et al. 2022).

In Krasnodar Krai, Russia, several efforts are currently underway to create geodatabases of municipal districts for updating and developing master plans for urban development. Digital technologies for analyzing and managing spatial data are being actively developed throughout the Russian Federation (Bezpalov et al. 2023; Safiullin et al. 2023).

Currently, there are no high-precision digital 3D models of CHH objects in Krasnodar Krai. There is no electronic resource that allows to familiarize a wide range of users with the features of the region's CHH, attract their attention, and encourage them to explore the history and geography of their native land and Russia (Kharkovskaya et al. 2023). The present project is aimed at creating an electronic resource (geoportal) with 3D models of CHH objects and their detailed descriptions, as well as options for organizing visits and learning about them as part of tourist and excursion activities.

The purpose of the current study is to validate the methodology of creating a geoportal of digital twins of CHH objects.

METHODOLOGY

Objects for the study were selected proceeding from the possibility and expediency of their digital modeling defined by the criteria of accessibility, physical dimensions, and type of the object (a construction, building, complex of objects), as well as exclusivity and tourist and excursion value. As a result, the objects chosen for the study are the Church of Iveron Icon of the Mother of God and monument-arch in honor of the 50th anniversary of the Psekup mineral waters.

To create digital twins (3D models) of these CHH objects, stereo photographs were taken with a ground digital SLR camera. Stereo photography was accompanied by cartographic and geodetic measurements to determine the dimensions of the objects. Measurements were taken between the points of rigid contours identifiable on the images.

The desk process of creating a 3D model proceeded in several stages. The first stage includes the preparation and selection of photos, during which photos are equalized by brightness and tone and converted from RAW format to processing format, and unsuccessful shots are rejected.

Photos of the modeled object with a longitudinal overlap of 70-80% and a transverse overlap of 40-50% were uploaded to the Russian-licensed software Agisoft Metashape.

RESULTS

In the first stage**,** masks were applied to each image to remove noise and extraneous objects from the model. On average, about 20 images were used to create the model.

Figure 1. Application of masks to the photographs (in the photo: monument-arch in honor of the 50th anniversary of the Psekup mineral waters)

The software finds common points in the photos and uses them to determine all camera parameters: position (to scale), orientation, and internal geometry (focal length, distortion parameters, etc.). The results of this stage are a sparse cloud of common points in the 3D model space and data on the position and orientation of the cameras.

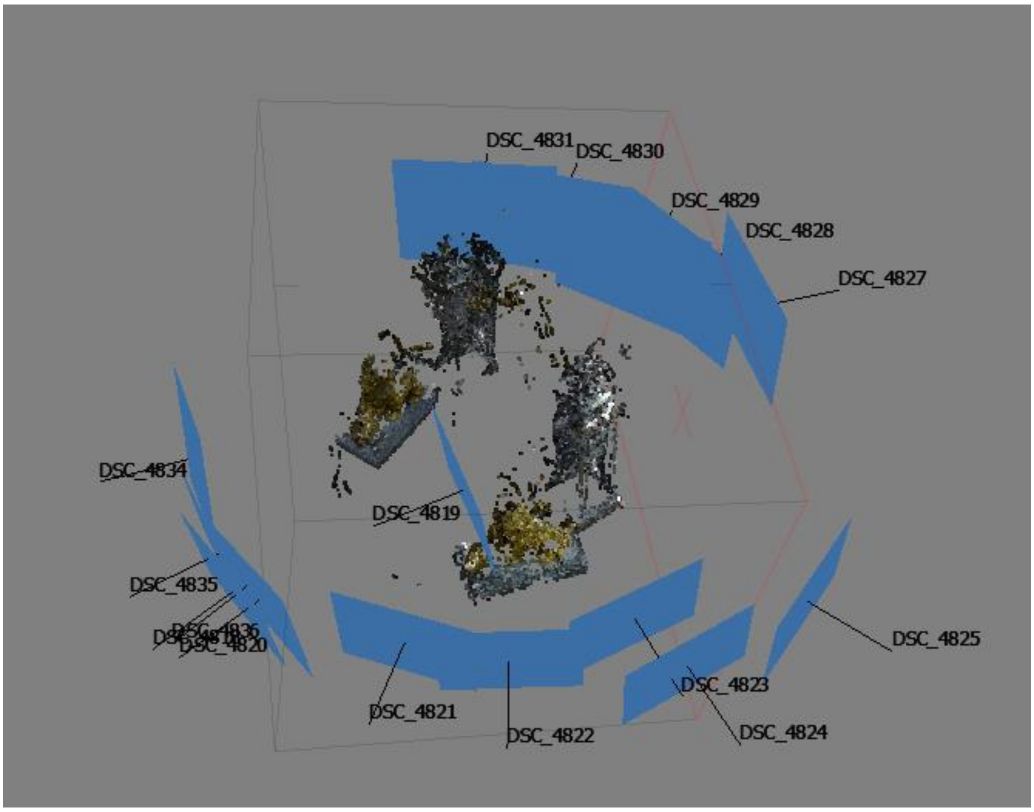

Figure 2. Common point cloud in 3D model space and camera position and orientation data

The set of data on camera position and orientation is used at further states of processing (Klyuev et al. 2022).

Constructing a dense point cloud. The dense point cloud is built in PhotoScan based on the calculated positions of cameras and the photos used. The dense point cloud can be edited and categorized before exporting or moving to the next stage of creating a 3D model.

Building a polygonal model of the object. The third stage is building a polygonal model that describes the shape of the object proceeding from the dense point cloud (Shirjaev et al. 2023). In addition, the model can be built quicker using only the sparse point cloud. Agisoft Metashape offers two basic algorithmic methods for building a polygonal model: a height map for flat surfaces (such as landscape or bas-relief) and an arbitrary for any type of surface. Sometimes the model needs to be edited after it has been built.

Object texturing. The final step involves texturing and/or constructing an orthophoto. Several methods of model texturing are available.

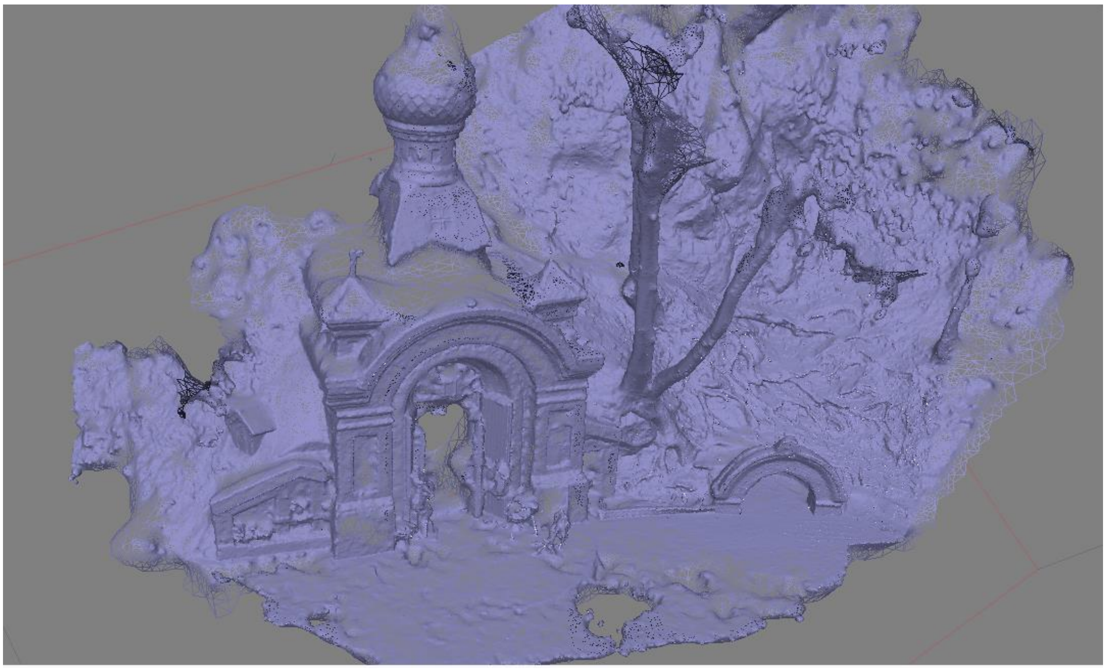

Figure 3. 3D model of the Church of Iveron Icon of the Mother of God (monochromatic visualization)

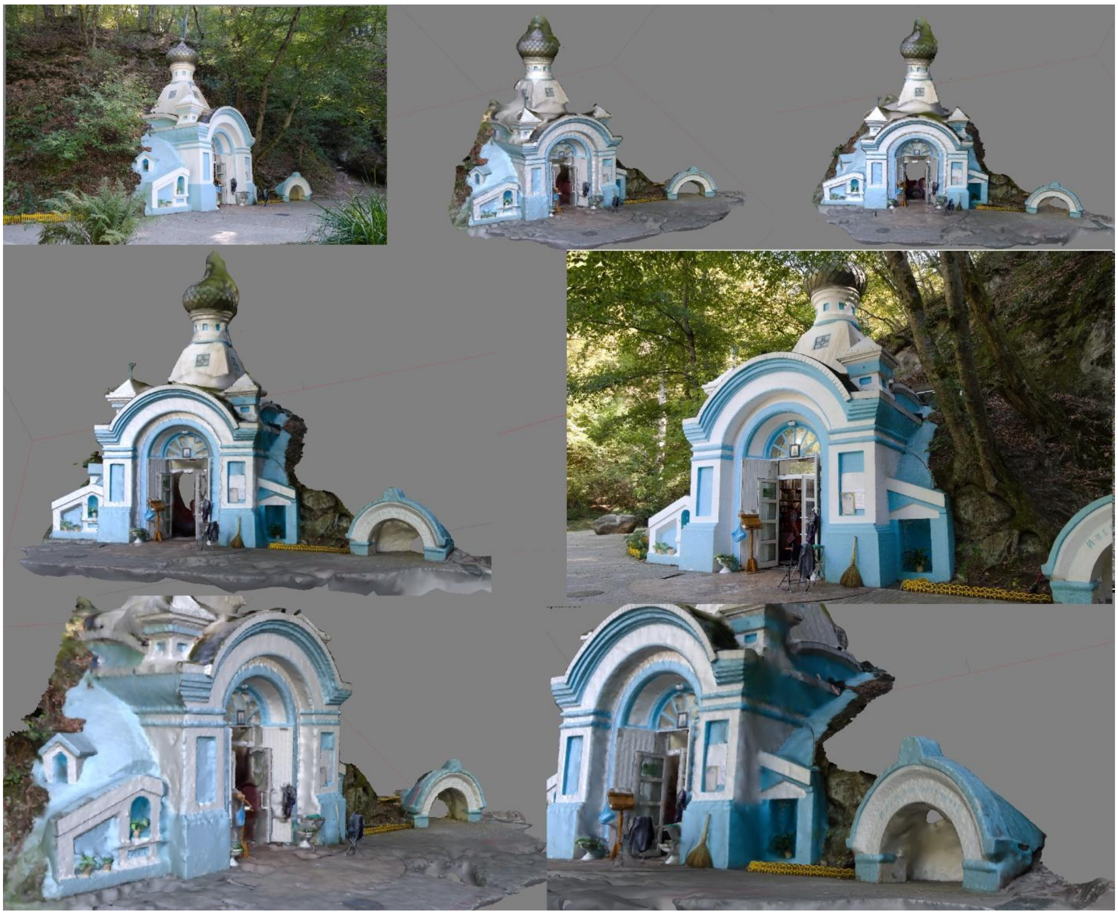

Figure 4. Photographs and a textured 3D model of the Church of Iveron Icon of the Mother of God

Setting the coordinate system**.** Several applications of the software are associated with the ability to set a coordinate system (Xiang et al. 2023). Specifying a coordinate system establishes the correct scale, allowing measurements of volume or surface area and easy loading of the model into geographic information programs. Some features (e.g., exporting a digital relief model) are available only after specifying a coordinate system. PhotoScan allows setting the coordinate system either by reference points on the surface or by camera coordinates. In both cases, coordinates are defined on the Reference Points panel and should be either loaded from a separate file or entered manually.

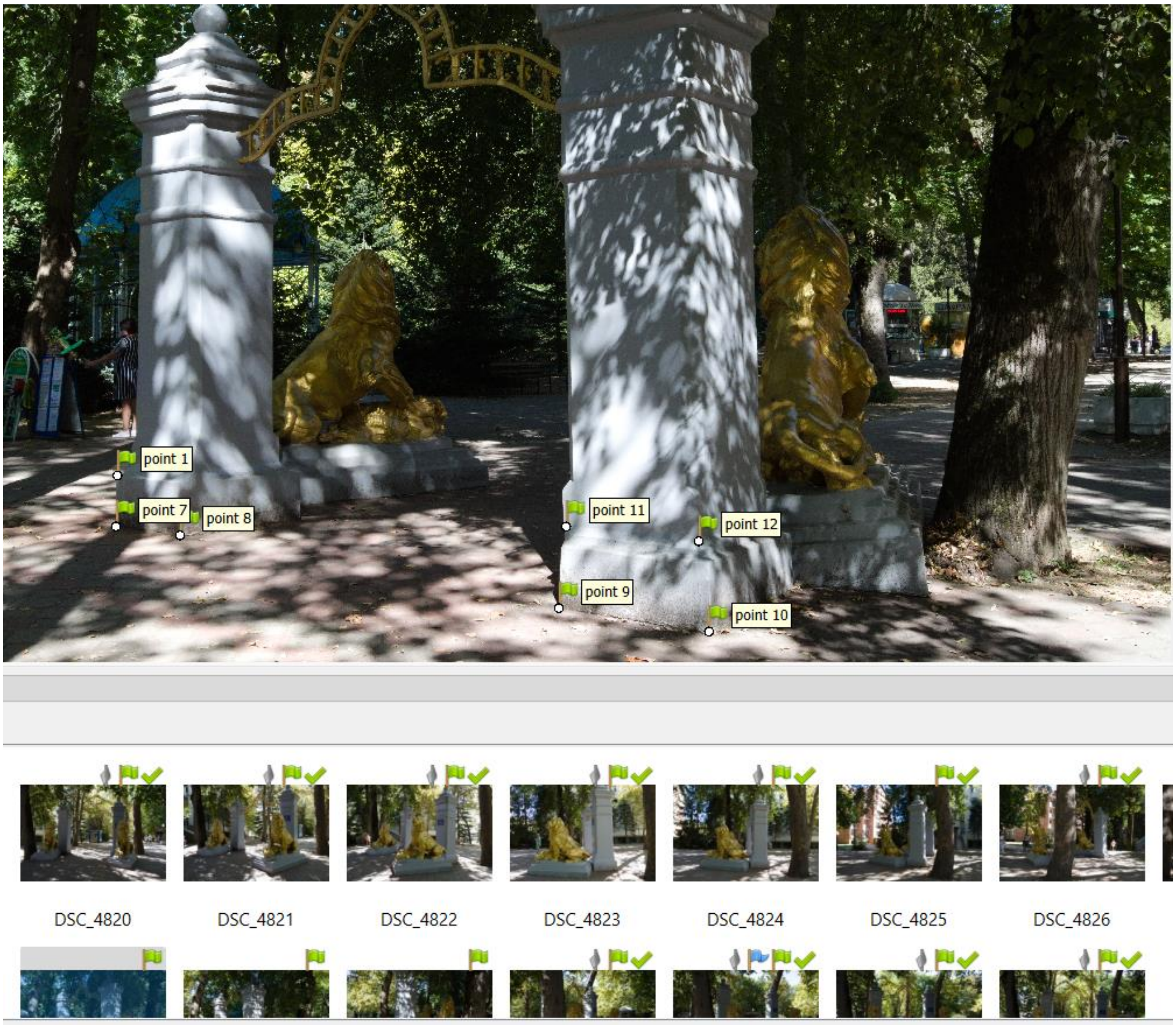

Figure 5. The process of setting reference points-markers (on the photo: monument-arch in honor of the 50th anniversary of the Psekup mineral waters)

In the case of using reference points on the surface to set the coordinate system, it is required to set the projections of reference points on the corresponding images. Markers on the surface usually provide more accurate georeferencing than telemetry data. PhotoScan uses reference points to set the coordinate system, optimize photo alignment, measure distances and volumes, and align blocks when using the respective mode. The position of markers is determined through their projections on the source photos. To define the position of markers in 3D space, their position has to be specified on at least two photos. The more photos are used to specify marker projections, the higher the accuracy of positioning. To specify a coordinate system based on marker points, position in space must be specified for at least three points. PhotoScan supports two modes of reference point placement: manual and automatic placement. In manual mode, marker projections must be set manually on each image where the marker appears. Manual placement of marker points does not require building a 3D model and can be done even before photo alignment. In the automatic mode, the marker projection is set by the user on only one image. PhotoScan automatically projects the corresponding ray on the model surface and calculates marker projections on the remaining photos. Marker projections defined automatically can be later manually adjusted on individual photos to increase positioning accuracy. The automatic marker placement mode requires prior reconstruction of the 3D model. Automatic marker placement usually speeds up marker positioning and reduces the probability of incorrect marker placement. This mode is recommended in most cases unless there is a specific reason to reject this approach.

Image alignment optimization. At the photo alignment stage, PhotoScan calculates parameters of internal and external camera orientation. This procedure is based only on the data contained in the images, which may lead to some errors in the obtained parameter estimates. The accuracy of final estimates depends on several factors, such as the percentage of overlap between the photos and the shape of the surface of the object under examination. These errors can lead to nonlinear deformations of the final model. In the georeferencing stage, the model is subjected to linear transformations using seven similarity transformation parameters (three translation parameters, three rotation parameters, and ome stretching/compression parameter). These transformations can compensate for only linear distortions of the model. The result of non-linear distortions cannot be eliminated by this approach. This is usually the main cause of errors in model georeferencing. Possible non-linear distortions during the alignment step can be addressed by optimizing the sparse point cloud and camera calibration parameters based on the known reference coordinate values. In this optimization PhotoScan recalculates point coordinates and camera parameters, minimizing the sum of errors in design and alignment by reference coordinates (ground control points and/or camera coordinates). To achieve better optimization results, it is recommended to edit the sparse point cloud by deleting the points known to be incorrect in advance. Georeferencing accuracy can be significantly improved through this optimization process (Agisoft, 2016).

CONCLUSION

The work on creating an electronic resource with high-precision digital 3D models of CHH objects of Krasnodar Krai will allow a wide range of users to familiarize themselves with these objects, draw attention to learning about them, and promote popularization of the region's history and geography.

The key result of the presented study can be considered the proposed and tested algorithm for creating a digital model of a CHH object. A clear sequence of works is described, which makes it possible to estimate labor costs and plan time expenditures for various CHH objects in Krasnodar Krai. Based on such calculations, it is possible to precisely plan the timing of prospective work to create digital twins of CHH objects in Krasnodar Krai. An advantage of this method can be seen in the relatively low cost of the work performed. The main cost items are transportation costs, labor time, and licensed software. Finished models of digital twins of CHH objects can be published both in their own information space and in the existing databases of digital models. To popularize the digital twins of objects of Krasnodar Krai's CHH, it is advisable to post them on a wide range of digital platforms, both those specialized in publishing digital models and a digital resource dedicated to these models specifically.

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