

Article

# Digitization, Visualization and Accessibility of Globe Virtual Collection: Case Study Jüttner's Globe

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**Abstract:** The aim of the article is to prepare a model for making available metadata and digital objects of the new Globe Virtual Collection for the Map Collection of the Faculty of Science of Charles University. The globes are special cartographic documents; therefore, they are also described in a special way. The article deals with the digitization, visualization and accessibility of an old globe by Josef Jüttner from 1839, which comes from the depository of one of the most important central European collections. A simple model for a new virtual processing of the globe collection at Charles University is presented. SfM-MVS photogrammetry was chosen for digitization of the globe. The basic elements of the copperplate were set as basic parameters for image acquisition. Contrast, density, black line, line, dash and dot patterns and their complex use were observed for a good graphic design of the globe. Other parameters included a closer determination of the users for whom the resulting product is intended, as well as the profile of the users' behavior on the site so far. New metadata were extracted from the bibliographic description. The virtual 3D globe was integrated into the database using the Cesium JavaScript library. Metadata and a 3D model of the globe were linked together and made available to the general public on the Globe page of the Map Collection of the Faculty of Science of Charles University. A comparison of web browsers was performed focusing on the loading time of the 3D model on the website. New graphic elements were identified with the new processing. It was possible to read the factual information written on the globe. Different possibilities and limitations of metadata description, photogrammetric methods and web presentation are described. This good practice can be applied by other virtual map collections.

**Keywords:** historical cartography; 3D objects; SfM-MVS photogrammetry; digital reconstruction; metadata; globe visualization; virtual globes; Jüttner Josef



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## 1. Introduction

Thanks to digitization, the last ten years have seen a major breakthrough in the processing and accessibility of cartographic documents of Czech and foreign memory institutions. Cartographic cultural heritage is comprised not only of old maps, atlases and globes published before 1850, but also of unique manuscripts, works on original media or other rarities. Globes represent a specific category because their production in manufactories continued practically until the middle of the 20th century. Therefore, it is safe to assume that so-called unique globes were being created until 1950.

Digitization—composed of all its essential elements, i.e., selection, legal aspects, meta-data [1–3], technology [4–6], grid data and repositories [7,8]—appears to be the key tool for protection, archiving and enabling public access to globes. This viewpoint is reflected in documents issued by governments and international organizations. The protection efforts are supported by major international institutions such as UNESCO [9]. The greatest attention is paid to the processing of, and ensuring access to, old cartographic documents,

which are among the most used but also the most endangered segments of cartographic cultural heritage [10]. It is due to this reason they need special protection.

Many map collections in Europe, the United States of America and Australia are gradually digitizing and making accessible their unique holdings. Among the most important described and digitized map collections today are the David Rumsey Map Center [11] at Stanford University Libraries, the Leventhal Map and Education Center [12] at the Boston Public Library and the Map Collection at the National Library of Australia [13]. However, the description and digitization of globes is different from the processing of other cartographic materials. It is necessary to accurately prepare the sphere, as well as the description, geographical grid and texture of the continents, countries and other details. This is possible by creating a virtual three-dimensional model.

An example is the digital reconstruction of an old 16th century globe by Gerhard Mercator [14] for visitors to the Mercator Museum in Belgium [15]. One of the largest manuscript globes of László Percze with a diameter of 139 cm from 1862 has been digitized by the team of Mátyás Gede and made available in the Hungarian Virtual Globes Museum [16,17]. Valuable exhibits of Dutch pairs of globes by Willem Janszon Blaeu from the 17th century are also made available here.

The French National Library has also published a collection of digitized globes in the Gallica Digital Library [18], including a valuable terrestrial globe with a diameter of 24 cm by Martin Waldseemüller from 1506. Another unique item is an Arabic celestial globe from the 11th century.

Around a hundred digitized globes from various collections of the Czech Republic are published on the website of the Research Institute of Geodesy, Topography and Cartography [19]. Among old works, remarkable is a pair of globes by Vincenzo Maria Coronelli from the end of the 17th century with a diameter of 110 cm, owned by the National Library of the Czech Republic [20].

The problem of describing the globes and making them available was also addressed by the Map Collection of the Faculty of Science of Charles University, which was founded as early as in 1891. It acquired the status of the State Map Collection of the Czechoslovak Republic in 1920. Although this status was changed in the 1950s, the Map Collection has retained its importance. It contains 130,000 map sheets, 3500 atlases and 122 globes. More than 100,000 maps have been scientifically catalogued and 65,000 map sheets have been made accessible electronically [21].

The first attempts to make this part of the collection accessible were published already in 2013 [22]. Photographs of the globes with a brief description were gradually published on separate websites. They are dedicated to each exhibit, showing bibliographic, globographic information on the given specimen (metadata), such as the title, author, place and year of publication, as well as physical data describing the dimensions, the stand and material from which the globe was made. In the history of cartography, the Greenwich meridian was not always the prime meridian. Therefore, the position of the prime meridian (passing through, for example, Cape Verde or the Canary Islands) is also given for each globe. Old celestial globes depict the starry sky with allegorical representations of constellations in the form of animal or human figures.

Attempts at three-dimensional presentation have been published for the eight oldest globes. Researchers can virtually rotate the globe model, zoom in on it, view unique illustrations and notes, or read the historical names of cities and constellations. Due to the large volume of data, only smaller models have been presented so far. Projecting a globe into two-dimensional maps was also a topic of discussions. In 2013, an experienced team from the Belgian University of Ghent, led by Professor Philippe de Maeyer, who had already digitized the above-mentioned G. Mercator's globe [15] in the past, was recruited to collaborate. The digitized globes are presented in different formats (pdf, wrl and WebGL) and in different qualities, so that each user can view the model according to the capabilities of their technical equipment. It is often the case that researchers do not have the necessary browsers, programs or other equipment needed to quickly view the globes.

Physically, old globes are either not displayed or only rarely displayed so as not to damage them. The spheres were often made of plaster and paper and are therefore very fragile. The globes cannot be exposed to light or to changes in climate and temperature, or to human intervention in order to prolong their life. The high financial costs involved in restoration should also be mentioned, as it was not possible to make accessible the original blackened, damaged, cracked or illegible globes [23]. This has also created new re-paired objects that will need to be newly processed. In addition, through gradual acquisitions, the Map Collection of the Faculty of Science, Charles University, has obtained around 50 new globes in the last ten years. In digital format with verified metadata, re-researchers can zoom in on the globes at any time in great detail and verify a lot of the data.

The aim of the article is to prepare a model for making available metadata and digital objects of the new Globe Virtual Collection for the Map Collection of the Faculty of Science of Charles University. Therefore, the research question arose of how to describe the globes in a modern and effective metadata method and of how to digitally process and make them accessible. Simply put, how to digitally process and visualize the repaired and new globes quickly, easily, without major demands on other auxiliary tools and browsers, in order to make them efficiently accessible to researchers.

This article therefore deals with the digital reconstruction and visualization of globes and how to provide access to them. Good practice is demonstrated through a case study of the processing of a terrestrial globe by Josef Jüttner (1775–1848), originating from the repository of the Map collection of the Faculty of Science of Charles University.

### *1.1. Research of Literature and Existing Methods*

Knowledge of the original materials, the process of creating the globes and their individual components was a prerequisite of successful digitization. Numerous authors have studied this topic in the past [24–28]. Initially, the globes used to be of a smaller diameter. As the diameter became larger, it gradually became customary to create globes comprised of two hemispheres, which were made in molds. Gores were cut from a globe map printed on paper and carrying terrestrial or celestial content, and then carefully pasted onto a gypsum or cardboard sphere. The old globes were often supplemented with further instruments and aids such as the compass, the meridian or the horizontal circle. Degrees were engraved into the meridian circle to aid the reading of the latitude. The horizontal circle was usually made of wood and pasted over with paper with a calendarium printed on it [29].

The old terrestrial globes usually included a geographical grid. The choice of the zero meridian could vary—it would pass through the Azores or El Hierro Island in the Canary Islands. It was not until the late 19th century that the prime Greenwich meridian became the established norm.

In order to digitize the globes and provide access to them, it was first necessary to identify a suitable digitalization method and then apply it accurately and efficiently. The criteria for the selection of this method were to determine the overall geometry and small details such as drawings, grids, or captions on the terrestrial globe. Another important parameter to be taken into account was the size of the globe, which could range from 10 cm to 100 cm in diameter. In particular, the Map Collection of the Faculty of Science of Charles University contains old globes ranging from 8.6 cm to 113 cm in diameter. In the whole Czech Republic, according to Karel Kuchař's research, old globes have a diameter from 7.5 cm to 127 cm [30].

The physical mounting and the possibility of removing the globe from the base was equally important. Four basic approaches to the digitization and 3D reconstruction of old globes are described in the literature.

The first attempts focused on creating a high-quality texture and then displaying it on a spherical model. This method was described by [31]. Taking images of the globe was carried out sequentially, according to the geographical grid at regular intervals to ensure sufficient image overlap. The subsequent conversion of the images into a 3D model was

very +labor intensive. Each image had to be georeferenced separately using control points. Overlapping images rectified this way could be assembled into a complete mosaic in the shape of a sphere. This method has also been discussed in detail by [32,33]. This procedure involved some difficult manual handling of the globe. This involved dismounting the object from the base, expertly removing the meridian ring and placing the globe into a special static imaging device, where it was fixed and could be moved around on wheels.

The second approach was the creation of a 3D model on the basis of printed globe maps, as described by [17,34–36]. This method involved a reconstruction (rather than digitization) of the globe and its visualization on the Internet. In these cases, gores of the globe printed on paper were scanned. The digitized data obtained in this way had to be georeferenced using the intersections of the geographic grid to create a uniform (spherical) object with the texture of a globe. It was an efficient, accurate but very labor-intensive method.

A third variant was described by [37]. It involved laser scanning combined with the photogrammetric method. In this case, a real 3D globe was scanned and photographed. Laser scanning was used to define the final shape of the globe (sphere) and a texture was created from the photogrammetric images. The resulting globe models had a visible structure (e.g., continents, oceans, descriptions, etc.). Calculation problems may arise in relation to the resulting point cloud. Visible empty space appears in areas with a uniform texture, such as the oceans. This problem is addressed by [38], who used laser scanning data to fill in the gaps in the point cloud.

The last known method of processing three-dimensional objects is close-range photogrammetry. This method was tested by [15]. The gaps occurring in the point cloud were calculated using triangulation. This procedure of contact-free digitization and reconstruction of old globes was used by [39,40]. The testing of the relationship between varying image overlap sizes, the used focal length and the resulting accuracy of the 3D model was presented by [41].

Laser scanning and photogrammetry are suitable for creating a 3D textured model. Laser scanning is recommended when high accuracy over a large area is required. Photogrammetry is more suitable for documenting smaller objects and capturing realistic textures. A comparison of these methods according to the various criteria of equipment, data processing and accuracy are described, for example [42]. SfM-MVS photogrammetry appears to be a suitable method for 3D digitization of the globe, using the automatic techniques of Structure from Motion (SfM) and MultiView Stereo (MVS) to estimate a 3D model from overlapping 2D images. The creation of the 3D model takes three steps. (i) The automatic keypoints extraction from all images and matching across images using the algorithm Scale Invariant Feature Transform (SIFT). SIFT allows for a comparison of corresponding features under changes in the angle of view, scale, partial occlusion and changing illumination. (ii) SfM is used for the calculation of individual camera positions, orientations, focal lengths and relative positions of corresponding features. This step is known as bundle adjustment. (iii) The dense point and 3D surface (model) are determined based on known camera parameters using MVS. The quality and accuracy of the 3D model depends on the image's quality [43].

In general, camera calibration must be performed for non-metric cameras. This determines the Internal Orientation Parameters (IOP) that are necessary for image processing—i.e., the focal length, the coordinates of the camera principal point, and the radial and tangential distortion coefficients. The radial distortion of the lens significantly affects the geometric accuracy of the result. For non-metric cameras, the distortion at the edges of the images can be as high as 200  $\mu\text{m}$ . In the case of high image overlap, self-calibration can be used [44,45]. The digitization parameters are related to good map design. The use of the black line, black dash and black dot in cartography is described [46]. Web presentations represent an increasingly popular means for the public to access three-dimensional globe models in a virtual environment and work with them. These presentations can be created in three ways.



The first option is to make the digitized globes accessible in the form of georeferenced maps using one of the web services designed for this purpose. The Tile Map Service is an example of such a service [33].

The second option is to view a three-dimensional model in one of the graphic formats directly in the web browser. The graphic format determines how and what data are saved in the file. Each format has its own specifics and is suitable for a particular application and purpose. The most commonly used 3D graphic formats are obj, x3d or glb.

The obj format was developed in 1990 by Wavefront Technologies. It is an open text format that describes the geometry of one or more objects. The color and texture data information is usually stored in a separate mtl file, which is distributed with the original obj file [47].

This format is used in most 3D software such as Maya, Blender and 3ds Max. It is suitable for exporting objects, but not for exporting animations [48].

The glb format is a binary file format used to share 3D data. It contains geometric data such as vertices, surfaces and normals. However, it may also contain additional information about models, lighting, materials and animations. The glb format is developed by the Khronos Group, a non-profit consortium that creates open standards in 3D computer graphics or virtual and augmented reality [49].

Extensible 3D, abbreviated x3d, is an open format from the Web3D consortium. It allows you to store 3D objects and scenes. It is used, for example, for the visualization of scientific data, multimedia presentations or websites with 3D content. It replaces and extends the original Virtual Reality Modeling Language (VRML) format, which was designed primarily for virtual reality, to include new features [50].

The glb format has the advantage over obj and x3d in the better rendering of object shape. This is because it uses not only triangular meshes, but also points or edges. All the elements of a 3D scene are stored in one compressed file, so it speeds up loading in web browsers.

In terms of technology, HTML5 programming language is used nowadays, which allows for rendering graphical elements directly in the core of the web browser [51]. Open-source libraries based on JavaScript and WebGL (Web Graphics Library) web standard are used to render 3D graphics [52]. JSC3D Viewer, the Google Earth plugin or the JavaScript libraries Cesium and X3DOM appear to be the most widely used tools [51,53].

The last option for presenting a 3D model of a globe is the 3D pdf format. This is a document type created by Adobe in the 1990s that can be opened in the freely available Acrobat Reader. This presentation method allows 3D objects to be displayed, as well as zoomed in on, rotated from any angle and interactively manipulated [54].

One of the most popular options for displaying a virtual globe in a web browser is the Cesium JavaScript library. It is available under the Apache 2.0 open-source license for commercial and non-commercial use. It supports many formats such as obj, glb, 3D tiles and more. It is a solution that supports the modification of globe display parameters—including the combination of map layers with a digital model of the Earth's relief—by calling the CesiumJS functions. Cesium makes full use of web technologies, and, unlike software solutions, it does not require any installation, only a web browser [51].

JSC 3D Viewer is a freely available browser based on JavaScript technology. The program uses spatial models that are stored in an obj file. The model can be rendered using points, triangles, a flat surface, smooth flat surface or may be textured. The web browser loads the entire model, saves it in its cache memory and displays it. JSC Viewer is easy to implement in a web browser without the need for any installation [55].

X3DOM is a program library created in JavaScript. It allows for the easy integration of three-dimensional models in x3d formats directly into the web browser. Using the JavaScript language, it is possible to modify the parameters of the scene view, as well as the appearance of the 3D model and more. Like Cesium and JSC 3D Viewer, X3DOM does not require the installation of plugins. The library can be used free of charge for

non-commercial and commercial purposes. Detailed description of the X3DOM library is described [56,57].

It is necessary to specify the end users and their demands for making the globes available on the web. The added value of virtual globes compared to traditional objects can be summarized as follows: interactivity, navigation, object as interface, exploration, customizable to user needs, updatable, dynamic animation, multimedia integration [58]. The authors of the web presentation drew/derived primarily from good practice examples of other virtual globe collections, as well as from communication with users. The necessary financial, human and time resources have not yet been obtained to carry out a detailed survey of user needs. The web interface for viewing the globes contains tools related to the experience of cartographers and programmers. It has to be user-friendly and address their spatio-temporal questions for the answers they need to function in their daily life, employment or education [59]. It is assumed that users of the virtual globe collection have a basic level of technical knowledge and have an idea of how to use the online map or globe and also how to access the information. Most of these users are probably influenced by the availability of Google Maps [60]. In general, globe information offers many topics related to geography, cartography, history, astronomy or toponomastics. The restorers can also use the objects to repair and reconstruct globes. In this case, working with users is based on a partnership and collaboration with experts and is aimed at educational institutions. In previous years, the Map Collection organized a series of competitions for the public on the topic of georeferencing old maps. Therefore, it is known that most people interested in these cartographic materials access them from home in their free time and use the site for their personal use [61]. On the other hand, interviews with curators and teachers during school excursions in the Map Collection of the Faculty of Science of Charles University show that the globe's website is also used in teaching. Considering the demands on the quality of data transfer, it can be assumed that users tend to be well technically equipped, not only with good quality computers, but also with good data transfer speeds, as is common in the academic community.

Slow loading of the 3D model can be a significant limitation for working with web pages. If the model does not load in real time, the user may even leave the site and probably not return. Therefore, website speed optimization performance is an important parameter for making the 3D model available. Most web browsers offer a simple tool in their "Developer Tools" to assess a website's loading speed and weak points. Website loading time can be measured using three criteria: Domcontentloaded, Load and Finished. It is made possible thanks to WebGL's ability to work with so-called DOM (Document Object Model) elements [49,62]. DOM is an API allowing access to or modification of the content, structure or style of a document.

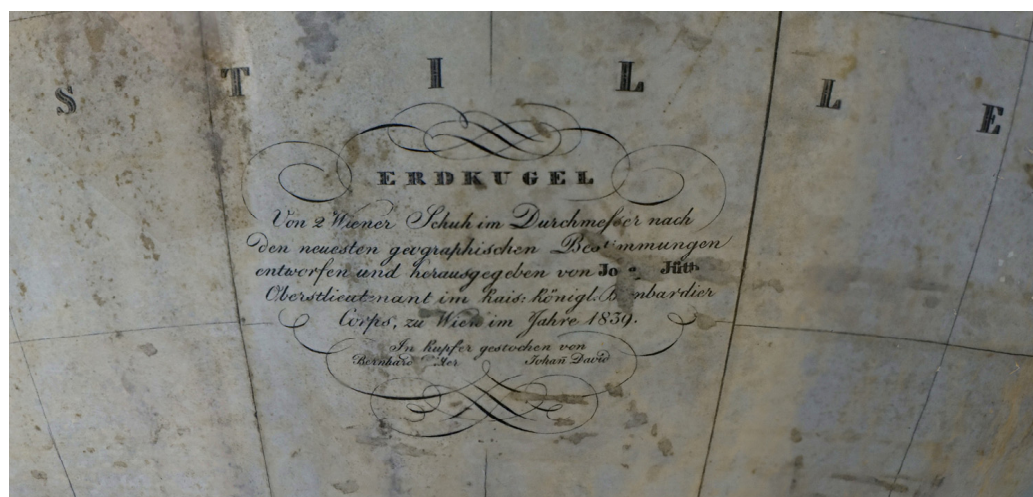
The "Domcontentloaded" event indicates the point in time when the DOM has been completed but the external resource has not yet been loaded. The "Load" event indicates when each individual resource (img, glb, style, script, etc.) has been loaded into the browser. "Finish" refers to the period of time from the start and end of loading the 3D model data after each resource has been downloaded.

### 1.2. Case Study: The Globe of Josef Jüttner

A relatively large globe created by Josef Jüttner in the first half of the 19th century was chosen for the case study.

Josef Jüttner (1775–1848) was a mathematician and military cartographer of the Austro-Hungarian Army. He later worked in Prague as a globemaker and publisher [63]. He also published maps, for example *Grundriss des ... Hauptstadt Prag*, on two sheets (1811–1815). He created a 12-inch celestial globe in 1:29,000,000 (Prague, 1822, with Franz Lettany) and a new 12-inch celestial globe (1824). An armillary sphere called *Ringkugel* was published in 1828. The Jüttner-Lettany globe from 1822 was reissued in Prague in 1840. Jüttner continued to publish 24-inch pair globes in the 1836–1839 period. The terrestrial globe was republished in 1846 [64].

The subject of our study, i.e., the terrestrial globe called *Erdkugel*, with a diameter of 63.5 cm, a circumference of 199.5 cm and a height of the stand up to the brass meridian circle (measured perpendicularly from the base) of about 41.8 cm, originates from 1839. The full transcription of the German text of the cartouche containing the globe's title (Figure 1) and author reads as follows: *ERDKUGEL von 2 Wiener Schuh im Durchmesser nach den neuesten geographischen Bestimmungen entworfen und herausgegeben von Josef Jüttner Oberstlieutenant im Kais. Königl. Bombardier Corps; in Kupfer gestochen von Bernhard Bitter und Johann David.*



**Figure 1.** The German text of the cartouche. Source: Map Collection of the Faculty of Science, Charles University.

(Translated: The globe measuring 2 Viennese feet in diameter reflecting the latest geographical knowledge was designed and published by Josef Jüttner, Artillery Lieutenant Colonel; engraved in copper by Bernhard Bitter and Johann David.)

J. Jüttner published the work in Vienna at the scale of 1:20,050,000. Bernhard Bitter and Johann David from Vienna are listed as engravers [64]. The globe is made of gypsum, covered with a copperplate print of 18 paper gores and two polar spherical caps. A wooden lacquered tripod on wheels serves as the base. The globe is encircled by a brass meridian circle with engraved degrees ( $4 \times 0-90^\circ$ ). Furthermore, the instrument is equipped with a horizontal wooden circle illustrated by a calendarium and Zodiac signs.

A detailed metadata description in MARC 21 format was created for the Central Catalogue of Charles University. From it, the basic metadata for the web presentation of globes were extracted (in the Appendix A, Table A1).

The globe was restored in 2016 by Miroslav Šíroký as it was illegible and damaged in many places [65]. The stand had also seriously deteriorated. The repaired globe was inserted into a triangular base. Currently, the historical teaching aid is in excellent physical condition (Figure 2).



**Figure 2.** Overall view of the restored terrestrial globe by J. Jüttner, 1839. Source: Map Collection of the Faculty of Science, Charles University.

### 1.3. Contents of the Globe

Detailed imaging allowed for better identification of the contents of the globe. The zero meridian passes through the east of the island of El Hierro, i.e., through the Canary Islands. The globe features a geographical grid, and the major parallels are marked: the Equator, the Tropics and the polar circles.

The colors of the globe have already faded, especially those of the water bodies where the blue color is preserved only along the coasts. The Earth's surface was rendered in greyish brown. The elevation of the mountains was represented by shading in a brown color and the density of slope shading.

The contemporary content reflects the geopolitical division of the world and the geographical knowledge of the time. The globe contains information about geographical discoveries. For example, the following note appears regarding the Philippines: *Die Filippinen wurden im Jahre 1521 von Ferdinand Magellan entdeckt. Er und mehrere seiner Officiere wurden von den Eingebonen gehödtet. Sebastian del Cano setzte die eisen ach Ostindien fort, und war der erste der die Welt umsegelte. (Translation: The Philippines were discovered by Ferdinand Magellan in 1521. He and several of his officers were killed by the natives. Sebastian del Cano continued his voyage to the East Indies and was the first to circumnavigate the world.)*

India is named as *Hindostan*. Tibet, *Nepal*, the Himalayas (*Himalaya Gebirge*), the eastern Indian coast known as *Coromandel*, or the island of Sri Lanka (*Ceylon*) are also shown in the area.

In the east, the description of *Kamtschatka* is emphasized, and present-day Alaska, which was still part of the Russian empire known there as *Russisches America*, is seen.

The continents and the countries within them are marked selectively. Nevertheless, the globe map looks cluttered in some areas and on the coasts. The work also contains a detailed description of the countries in the United States of America (*Vereinigte Staaten*), marked by Roman numerals from I to XXX. Numbers are assigned similarly to the states in Mexico (I.–XIX.) and in Central America (*Mittel America*, I.–V.). In South America, the Amazon River is marked, as well as the following states: Columbia, Guyana and Brazil.

Australia is only presented as an integrated land body without any further geographic structure, just the older name for the territory, *Neu Holland*, is included.



In Africa, the Niger River, Lake Chad (*Der Tschad*) is drawn, but the Congo River is not yet described, which is consistent with contemporary knowledge. An infamous slave trading post is shown on the west coast of the African continent (*Gold Küste Slaven*, Figure 3). The Pacific Ocean is called *Das nordliche Stille Meer*.



**Figure 3.** Detail of the researched globe by J. Jüttner. Source: Map Collection of the Faculty of Science, Charles University.

2. Materials and Methods

The high-quality perception and interpretation of the work by the user is related to the appropriate parameters of digitization and three-dimensional visualization of the selected object. The basic rules of graphical map design were established in the middle 16th century in commercial Dutch printing houses. The design aspects (contrast, density, weight of black graphical elements, dot and dash pattern and comprehensive use of black line, dash and dot) are analyzed in [46]. The following parameters were determined for taking the images of the globe for the interpretation of these graphical features on the 3D model (Table 1).

**Table 1.** Parameters for image acquisition and 3D visualization of black-and-white graphics. Source: Map Collection of the Faculty of Science, Charles University.


Globe Design	Graphic Representation	Geographic Element	Pattern
Contrast	Short lines with horizontal dashes of coast, hatching of coastline, white and yellow land	Land and sea resolution	



Table 1. Cont.

Globe Design	Graphic Representation	Geographic Element	Pattern
Density (readability limits)	Varied groups of black elements, different density and various thickness of lines, dashes and dot sizes	Mountains, hypsography, coastline	
Weight of black graphical elements	Number of dots or lines, shades of grey, width of lines, changes in line thickness, size of dots	Edges of desert oases, hypsography, lakes, roads, state borders	
Dot pattern	Regular dots	Edges of desert oases, shallows around islands	
Line pattern	Fine line drawing	Rivers, coastline, outlines of countries, continents, roads, geographical grid	
Complex use of the black line	Elements tying together the graphic of the globe	Hydrographic network, coastline, roads, state border	
Complex use of the black dash	Regular and irregular delicate dashes in direction	Movement of flowing rivers, water surfaces, degrees of zero meridian, hypsography	

Table 1. Cont.

Globe Design	Graphic Representation	Geographic Element	Pattern
Complex use of the black dot	Elements tying together the graphic of the globe	Coasts (for islands, e.g., Bank von Neufundland), deserts (for oases), edges of unexplored areas (e.g., Antarctica)	

In accordance with the approach chosen to perform the digitization, a contactless imaging method was used to avoid damaging the surface of the rare and unique globe. Therefore, the globe was placed on a special static base, while the camera could move around it. The aim was to minimize any manual handling of the globe. A non-metric digital camera was chosen to perform the imaging. The camera must fulfil the following parameters: (i) be a high-quality image sensor with excellent detail rendering, (ii) be able to take images of high-contrast subjects, (iii) have a low level of noise, (iv) focus in low light conditions, (v) a high-aperture lens and (vi) greater depth of field.

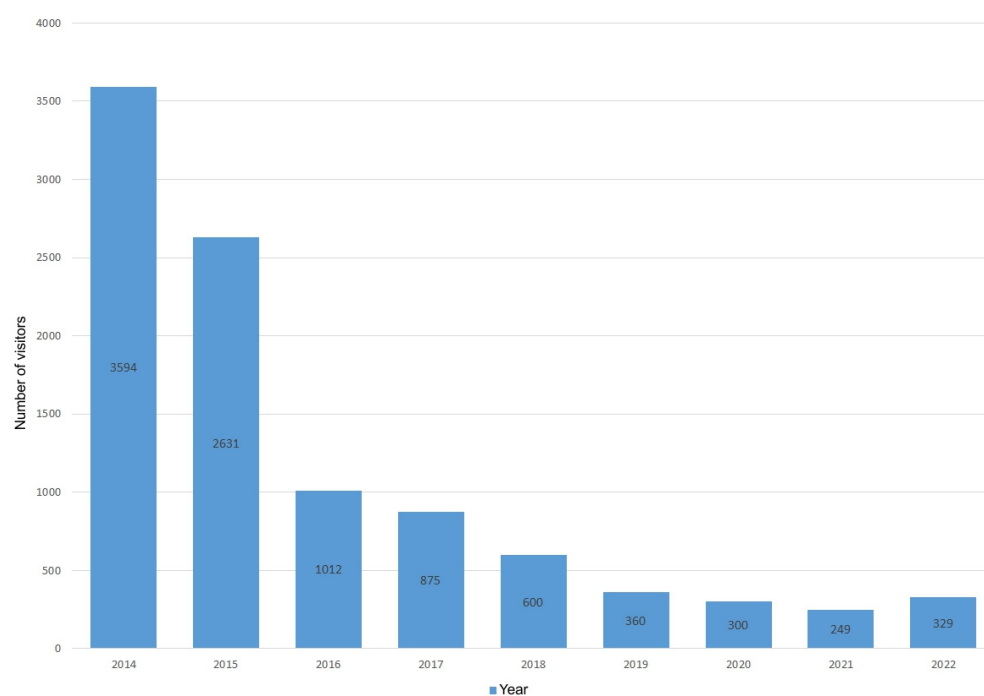
The same focal length and thus the same distance from the object was set throughout the photographing to maintain the constancy of the IOP. In order to capture all the detail, the globe was not photographed as a single whole but was split into smaller segments (Figure 4).



Figure 4. Dividing the whole globe into segments. Source: author, Agisoft.

In the Virtual Globe Collection, the data is cartographically and photogrammetrically modified against geographic information systems (GIS). Functionality will be deliberately limited and focused on users for whom analytical and visualization functions will be customized. The final users are non-expert GIS users who are able to use the interface independently and comprehensively, check functions and data and do not need instructions or a narrative workflow. They focus on the manipulation, analysis and presentation of data. The original data are processed raw and unmodified into the primary model during a short or long processing period. While non-experts use a basic interface, the control of functions and data is performed by the authors of the interface, because users need significant support, tutorials and a narrative workflow. The main focus is the visualization of globes; data must be modified and integrated into the web browser. Users work with a secondary model; the response time must be very short and the purpose of their work is very specific [57].

On the Map Collection globes website there is a counter tracking the number of visits. A “visit” is defined as viewing a page in a browser for a certain period of time, in this case 30 min. This means if a user returns to the site from the same computer after more than 30 min, a new visit is counted. It is possible to track user accesses since 2014 (10,800), weekly (average 17) and daily (average 6). Between 2014 and 2021, the average annual decline in visits was 30%. The highest number of visits was recorded in 2014 (3594) and the lowest in 2021 (249). In 2022, the number of users (329) will increase to approximately the 2019 value after the end of the COVID-19 measures (Figure 5).



**Figure 5.** The number of visits for the virtual globe collection in 2014–2022. Source: Map Collection of the Faculty of Science, Charles University.

The Cesium JavaScript library was used to display the spatial model on the web. This library was chosen due to its ability to display 3D file formats (glb, obj) and its easy implementation in a web browser. The ability of this solution to publish source files (the 3D model and the Cesium library) on a selected web server and the support of displaying the files in most web browsers were also important factors. The installation of the Cesium library on the server is not very demanding. The latest version of the installation files was downloaded from <http://cesiumjs.org> (accessed on 15 May 2022). A folder of approximately 35 MB in size contains all the necessary libraries and documentation. This folder and the 3D model file (glb) were uploaded to the web server and prepared for further

editing and basic setup. The detailed process of digitization, visualization and accessibility of the globe is shown in Figure 6.

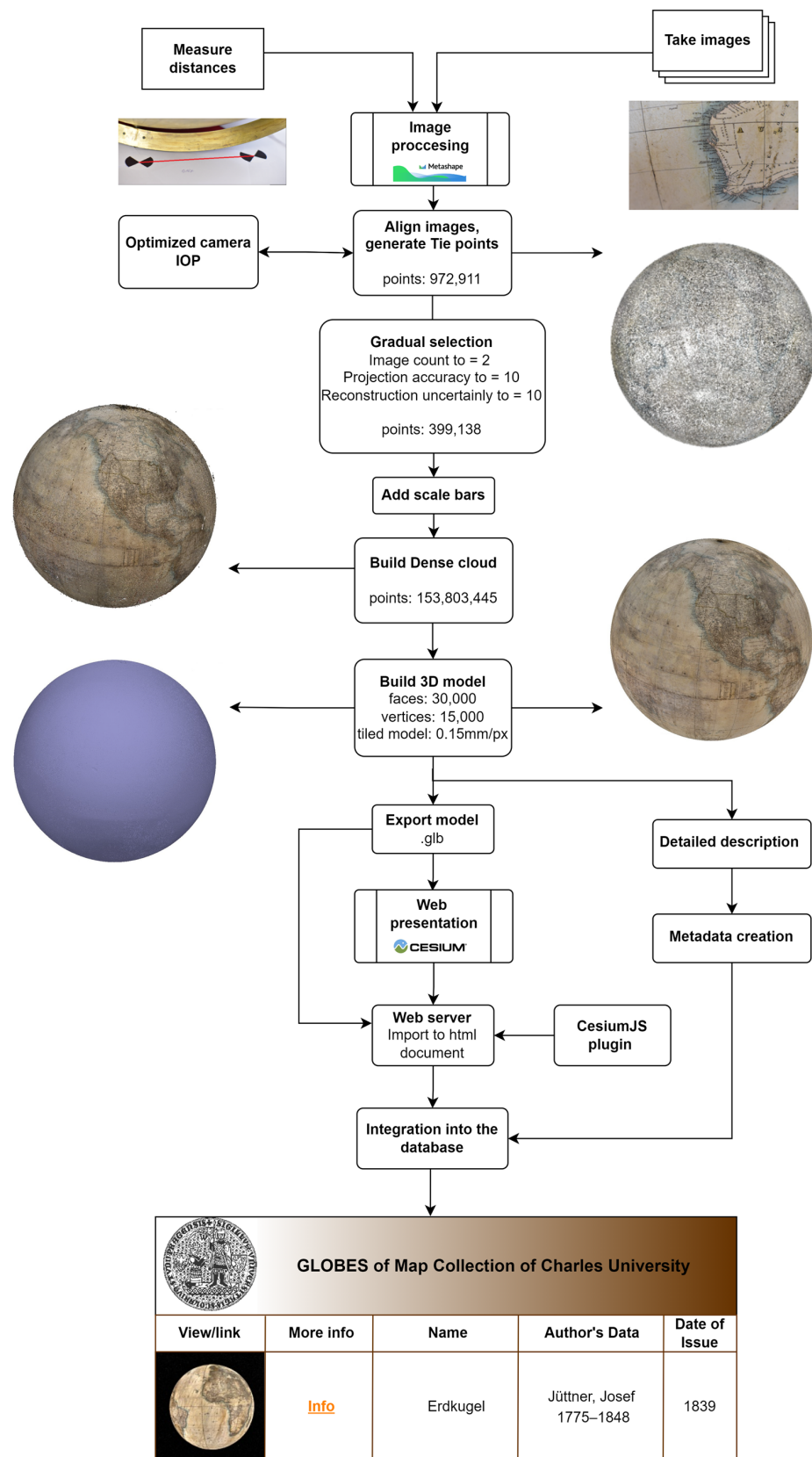


Figure 6. The processing steps of digitization, visualization and accessibility of the globe. Source: author.



### 3. Results

#### 3.1. Digitization of the Globe

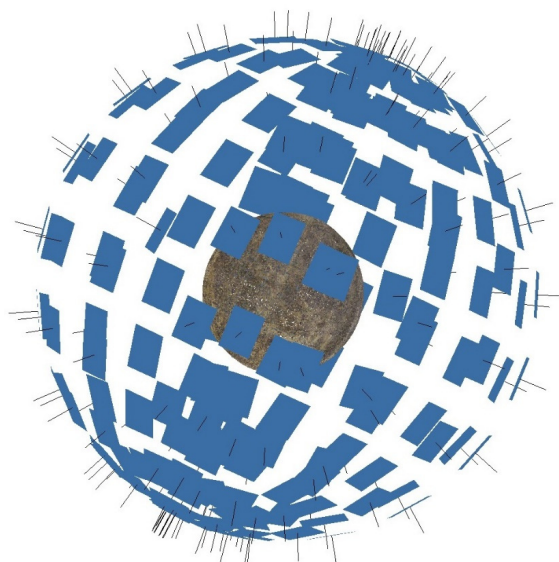
SfM-MVS photogrammetry was used to digitize and visualize the Jüttner's globe due to its size.

Imaging was performed with a Nikon D750 digital non-metric camera (DSLR) according to the principles of SfM-MVS photogrammetry, with a fixed focal length of 85 mm (Nikkor lens AF-S, 85 mm, f/1.4G, Nikon, Tokyo, Japan). This camera fulfils the conditions described in Materials and Methods. The images were taken in the aperture priority mode because the higher the f/stop, the smaller the opening in the lens; the greater the depth of field, the sharper the background. At the same time, the focusing distance was maintained the same, thus IOP did not change at all. The minimum focusing distance for this type of camera is 850 mm. In order to obtain the detail, it was necessary to reduce the focusing distance, so the extension tubes were used. The extension tubes contained no optical elements; thus, they did not affect the image quality or change the focal length (Table 2).

**Table 2.** Camera parameters. Source: The Nikon D750 manual.

Image resolution	6.016 × 4.016 px
Sensor size	full frame (35.9 × 24.0 mm)
Focal length	fixed 85.0 mm
F-stop	f/10
Pixel size	0.006 mm
Image format	raw/jpeg

Images were taken sequentially along the meridians with an 80% overlap. So a high overlap is necessary for the optimization of the camera (IOP calculation). The configuration of the images can be seen in Figure 7. Control points, i.e., round white-black targets, were placed around the globe and the distances between them were measured. A total of 820 images were taken in raw format. The sharpness and color of the images were additionally checked and edited (sharpening, white balance and color) in Zoner Photo Studio X. Finally, the images were converted into jpeg format for further processing.



**Figure 7.** Image configuration. Source: author, Agisoft.

The image processing was performed on a PC (Intel Core i7 3.8 GHz, 64 GB RAM, NVIDIA GeForce GTX 1650 SUPER, Win10) in Agisoft Metashape Professional (Agisoft) version 1.8.2.0, which is suitable for photogrammetric image processing and uses the SfM-MVS technique. The first step was the alignment of the images. First, feature points were



identified on the images and then linked across all images to tie points. Subsequently, a dense cloud was created. Point cloud cleaning was performed according to the parameters described in Figure 6. The size of the point cloud and the resulting model was determined using measured distances between ground control points. The next step is to generate a 3D mesh and textured it into a 3D photorealistic model (Figure 8). The results of the individual steps are summarized in Table 3. The resulting model was exported into a glb format.



**Figure 8.** 3D textured model. Source: author, Agisoft.

**Table 3.** Overview of processing results. Source: Agisoft.

	Number	Quality	File Size	Time of Processing
Tie points	points: 972,911/399,138	Medium	314 MB	1 h 49 min
Dense cloud	points: 153,803,445	Medium	223 MB	1 h 05 min
3D model	faces: 30,000 vertices: 15,000	Medium	84 MB	55 min

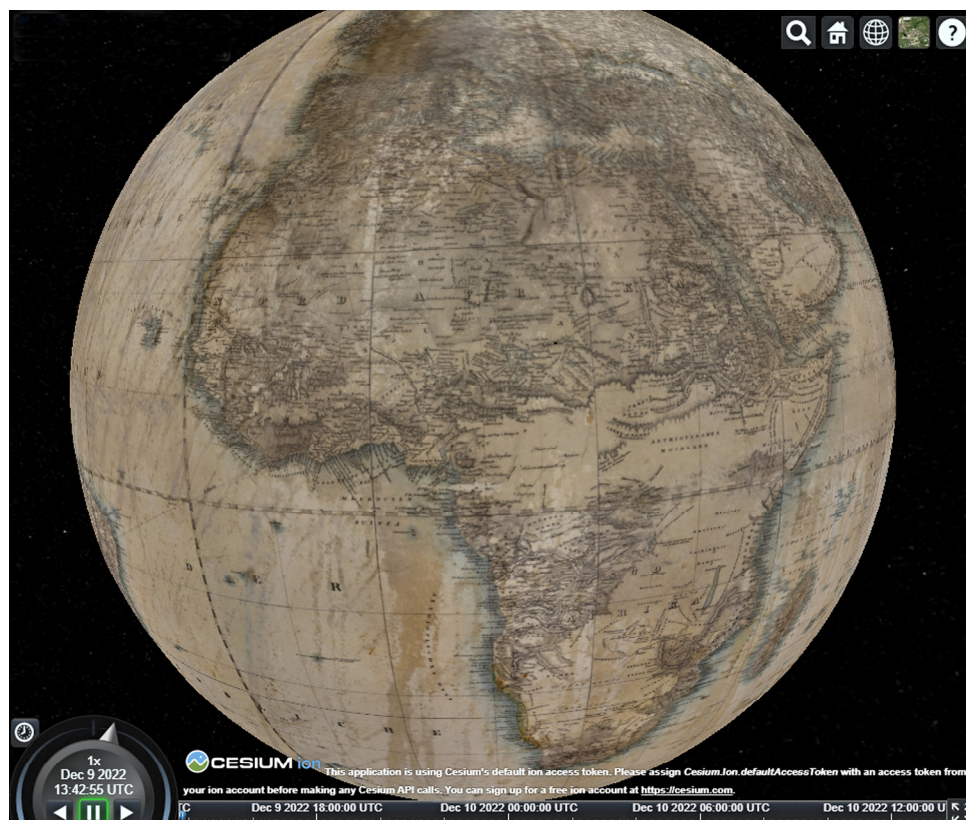
### 3.2. Accessibility of 3D Model

One of the goals was the interconnection of information, the 3D model and the presentation on the web. For the purpose of displaying the 3D model on the web, the glb binary format was chosen. It is a compressed file that was chosen for its faster loading in web browsers. The Cesium JavaScript library was used to display the model on the website.

The file with the 3D model in the glb format and the Cesium library source files have been uploaded to the web server of the Geography Section of the Faculty of Science of Charles University and are accessible to the public (Figure 9).

After entering the web address, the web browser first shows the basic interface of the Cesium application. This resembles a space environment in which a 3D model of the globe is subsequently displayed. The scene is reminiscent of a starry sky, in which the model evokes a planet. Due to the size of the file (14 MB), the user has to wait a few seconds before the model is loaded into the web browser.

The model can be rotated as desired, as well as zoomed in or out. The bottom bar, which is a standard part of the Cesium application, is in the form of a timeline and is used to adjust the lighting of the model (Figure 9).



**Figure 9.** Example of access to the globe in the web browser. Source: Map Collection of the Faculty of Science, Charles University, Cesium.

Different web browsers can affect the speed of loading the 3D model. Therefore, a comparison of web browsers was made focusing on the speed of loading the 3D model on the web. The loading of the 3D model data was tested in Chrome, Firefox, Microsoft Edge and Opera browsers. The loading time of the website with the model in the glb format (14 MB) was measured with Cache disabled based on three criteria: Domcontentloaded, Load and Finished. The tests were conducted on a PC Intel Core i7 3.8 GHz, 64 GB RAM, NVIDIA GeForce GTX 1650 SUPER, Win10 using the internet network of the Faculty of Science. Table 4 shows the average values after the loading of the 3D model data 30 times by each of the listed browsers.

**Table 4.** Browser-specific loading time. Source: Map Collection of the Faculty of Science, Charles University.

Browser	Domcontentloaded (s)	Load (s)	Finished (s)
Chrome	0.578	0.913	1.057
Firefox	0.213	0.885	2.000
MS Edge	0.589	0.871	1.000
Opera	0.636	2.000	2.000

The Domcontentloaded event indicates when the DOM has been completed but the external resource has not yet been loaded. Load indicates when each individual resource (eg glb) was loaded into the browser. Finished refers to the period of time from the start and end of loading the 3D model data to the download of each resource.

### 3.3. Metadata and Selected Aspects of the Globe

A unique description of the Jüttner globe has been created, which has not been done to such an extent before. Based on this, user metadata were created (Table 5). These metadata provide information about the globe and its 3D model. They contain the following

items: author, publisher information, scale, physical description of the globe, dimensional information, geographic grid, material, printing technique, color, format information, size and web presentation of the 3D model and more. The results have been integrated into the globe database of the Map Collection of the Faculty of Science of Charles University on the website [66]. In this way, the metadata, image information and 3D model of the globe have been interlinked and made accessible to the general public in Czech and English versions (the 3D model and metadata can be accessed at [http://www.mapovasbirka.cz/globy/english/index\\_eng.html](http://www.mapovasbirka.cz/globy/english/index_eng.html); Supplementary Materials).

**Table 5.** Globe and 3D model metadata. Source: Map Collection of the Faculty of Science, Charles University.

Information about the Globe	
Title	Erdkugel [cartographic document]/von 2 Wiener Schuh im Durchmesser nach den neuesten geographischen Bestimmungen entworfen und herausgegeben von Joseph Jüttner Oberstlieutenant im Kais. Königl. Bombardier Corps; in Kupfer gestochen von Bernhard Bitter und Joh. David.
Author's Data	Jüttner, Josef, 1775–1848
Engraver	Bernhard Bitter and Johann David from Vienna
Publisher	Zu Wien: Joseph Jüttner, 1839
Scale	1:20,050,000
Physical Description	1 globe: in color, copperplate, on a wooden stand with a tripod, a brass meridian circle with an engraved scale, a wooden horizontal circle with zodiac signs; 63.5 cm in diameter.
General Comments on the Globe Height	Globe diameter: 63.5 cm, Globe circumference: 199.5 cm, Pedestal height: 41.8 cm, Total height of the globe: 105.3 cm.
General Comments on the Prime Meridian Position	The Prime Meridian passes through the Canary Islands.
Geographic grid	The globe has a geographical grid, and the major parallels are marked: the Equator, the Tropics, and the Polar circles.
Color of watercourses	Blue
Color of Earth's surface	Grey-brown
Altitude	The altitude of the mountain range is represented by shading in brown and the shading density of the slopes.
Material	Gypsum
Printing technology	A copperplate print of eighteen paper gores and two polar spherical caps.
Language	German
Legend	No
Restoration year	2016
Restorer	Miroslav Šíroký
Globe owner	Map Collection of Charles University
2D model	Link to the 2D presentation of the globe.

**Table 5.** *Cont.*

Information about the 3D Model	
Comments on the 3D model creation	The globe model was created using the photogrammetric method in the Agisoft software.
3D Model Format	glb
3D Model Size	14 MB
Web presentation	Due to the size of the model (14 MB), it is necessary to wait a few seconds for the model to load in the web browser. By using the slider in the bottom horizontal bar in CesiumJS, you can change the direction of the globe model's lighting.
Genre/Form	Globes
Autor of 3D Model	Map Collection of Charles University
3D model	Link to the 3D model of the globe.

The detailed photogrammetric processing by J. Jüttner for the terrestrial globe revealed completely new details, which were previously invisible to the human eye. Patterns for black dots, dashes and lines were identified. The dots were used to represent desert oases and also shallows around smaller islands, for example in the Pacific Ocean. The lines were used to represent elevation, as landscape dashes, to indicate the rivers or to separate administrative areas on the map. The lines were used to represent the outlines of continents, lakes, rivers and roads. The rivers have thinner simple lines at their headwaters and thicken towards the estuary, where they diverge into several rivers in the estuary.

The density of the graphic elements was used to highlight the elevation where the lines thicken or even cross; then, in the case of dense dots, the edge of the oasis is marked. The artist achieved the contrast of the graphic by depicting the light area and the blue edges of the sea along the coast and by using short parallel lines. The complex use of the black line on the globe map is visible in the elaborate river networks. Irregular lines in the direction of flowing rivers refer to the complex use of lines. The complex use of the black dot is particularly visible in desert areas, where small and large, dense and sparse dots are depicted to achieve the effect of grey and dark grey.

A very interesting and new result is the visibility of factual data on the globe, which were previously not visible to the human eye. They open completely new possibilities of using this cartographic artwork. They reflect the contemporary state of scientific geographical knowledge. Geographical discoveries with names and dates are depicted here, e.g., the discoveries of W. Barentze (von Barentz 1596 entdeckt—Figure 10, Neu Seeland von Abel Tasman entdeckt 1642, Neu Georgie. Entdeckt von Roche 1675, wieder aufgesucht von Cook 1775 u. Bellingshausen 1819).

The territory of the Unknown Land (Unbekannte Laender) is depicted in the area of the African continent (Unbekannte Laender). Curiously, there is a description of the occurrence of giraffes (Ebene voller Giraffen) in southern Africa (Figure 11).

The previously mentioned dashed lines depicting national borders show the contemporary geopolitical division of the world. It is also possible to recognize detailed descriptions of contemporary German geographical names (Figure 12). This is given in normal type, capitals, block capitals and italics. The font size and fillers are also differentiated according to the meaning. Especially on the coast, the descriptions of ports are so dense that they resemble old portulan maps (Figure 11). Toponyms in Europe are so oversaturated that they are almost unreadable (Figure 13). The author was obviously aiming for completeness, but a bit of generalization would be appreciated by the user.





**Figure 10.** Barentze' discovery—von Barentz 1596 entdeckt. Source: Map Collection of the Faculty of Science, Charles University.



**Figure 11.** The description of the occurrence of giraffes. Source: Map Collection of the Faculty of Science, Charles University.





has occurred, especially in the upper parts, i.e., in the northern hemisphere. Each digitized globe may be important for understanding parts that are already damaged or unreadable on another globe. Therefore, there should be no obstacle to digitizing the same globe by the same author and from the same year. On the other hand, it is desirable to digitize as many of the available old globes as possible for successive comparisons, which we lack so far.

#### 4. Discussion

Many globes contain very little descriptive data of their own. Therefore, good quality visualizations can play a crucial role in the identification of a particular globe, especially in the case of older works. The virtual rotation and zooming of the globe or the celestial sphere make it easier for the researcher to read and verify the title, author and publisher details, as well as other supplementary texts that can be found on old globes. Such texts contain information about the history of the globe, or the state of geographical and cartographic knowledge at the time of the work's creation. Researchers can usually discover a lot of details that map collection staff cannot process when creating general metadata.

The digitization of globes is a significant contribution to the creation of scholarly digital editions (SDEs). They are a valuable historical cartographic source for many specialists. The digital globe edition in the web environment provides and integrates three levels of data and information, namely pictorial (globe as an image), factual (globe as a source of information) and secondary (globe metadata).

A globe, seen as an image or object, also represents a map when turned into a two-dimensional image. It is possible to add additional information or make a link to the original globe map image, if available. Globe maps are also often used to reconstruct unavailable old globes. However, this fact needs to be mentioned in the metadata in order not to confuse researchers. Old globes are interesting art objects illustrated with not only map symbols and compass roses, but also with animals, people, sea monsters and large sailing ships. The question remains of how to describe individual images on the globe or how to search for them automatically.

Old globes are not only cultural artifacts, but also a source of much factual information for historians, librarians, geographers, cartographers, philologists, teachers, artists and others. They can be used to examine information related to the environment, ecology or socio-economic phenomena such as land-use development and changes in or reconstruction of river flows or coastline shapes. They also record geographical names as well as cultural, political and economic facts. They are an important source of information on the stage of development for technology and surveying and for cartographic knowledge at the time of the document creation. Last but not least, they are an essential study material for the history of the development of science and scientific instruments. Here, the instruments can be connected to similar ones or to information on the development of science and technology in a given period (for example [67]).

As a source of factual information, the globe offers specific data, whether provided on a physical, political or celestial map. It shows rivers, ponds (some no longer existent), the shape of the coastline, which was also subject to changes, or sea currents. There are mountains and mountain ranges with the information, names and elevations of the time. There are images of woodlands, often depicted with very specific, unified features. There are historical toponyms. Philologists will appreciate the possibility of studying the development of the national geographical nomenclature over time. The extent to which descriptions and comparisons of historical toponyms on globes should be carried out remains a matter for discussion, and how to directly link the search for unified toponyms with the digital globe is also open for debate.

The map legend explains to the researcher the size and status of settlements, the economy and the political context. It may also contain statistical information. It should be transcribed in detail in all its original language versions and ideally also translated into the current language. All this can serve to annotate the globe in detail.

Celestial globes are important for the history of astronomy. Astronomical globes depict ancient constellations, allegories, ideas about the size of stars and so on [68]. For celestial globes, it will be necessary to address the issue of the unification of nomenclature so as to avoid any confusion of terms. The history of globes is also connected with decorations in the ceremonial halls of aristocratic mansions, in monastic libraries as a symbol of education, etc. Historians or archivists can research the history of ownership, or the actual paths taken by these art objects and the reasons behind this movement. The projected globes could theoretically be linked to information on original mansions, castles, chateaus or presentation libraries, with their history and interiors.

Globes have been used as teaching aids since the 19th century and were usually supplemented with instructions for use and examples for teaching geography. They are valuable for research into the history of the didactics of geography and mathematical cartography. They acquaint researchers with the state of knowledge in the field and the quality of teaching at various types of schools where these aids were compulsorily introduced. In this connection, it is also possible to examine how these aids are promoted by the ministries of education, and how well the schools and school offices are equipped. Comparisons can also be made within different regions. In this case, the digital globes could be supplemented with full texts of scanned manuals, textbooks, ministerial decrees or links to archival material, all in compliance with copyright and proprietary rights. Examples of period school offices can also shed light on the history of the use of globes.

Globes provide information on cartographers, engravers, translators, publishers and makers. Cartographers who produced globe maps were usually involved in the production of old maps, and this production complemented their wider activity in publishing maps, atlases and globes. This information offers a wide range of options for making links to digitized biographical dictionaries, bibliographies of authors, information about their lives, and their images.

Additional factual information can be obtained in the fields of book culture, the history of publishing houses, their production and the production of school geographical aids in the region concerned. Of equal interest is the development of trades, the origins of a company and the beginning of and the reason behind the production or sale of a globe. This information retrospectively helps to identify the missing data on the date of the publication of the document. The researcher can also examine the printing techniques used to make the globe map. If in some cases the printing plates have survived, then valuable hands-on experiments can be made with reprints of the work. Even without an imprint, it is possible to reconstruct no longer existing globes that have survived only on printing plates and to use them as a source of new information. This is why printing plates and stones also become items of map collections. Here, it is quite appropriate to make a link to dictionaries of printers, publishers and companies involved in the publication of globes or teaching aids, as the case may be.

Information about the manufactories producing globes is essential for the history of the industry. Of interest to humanities studies is the impact of the war on small manufacturers and education systems, and the interventions of totalitarian regimes and censorship in the production and creation of these teaching aids. Some patented inventions, such as composing globes, are an interesting part of the history of patents [69].

Furthermore, it is possible to study the development of geographical instruments in their entirety; that is, globes, both terrestrial and celestial, planetariums, armillary spheres and sololunaria. The question is how to digitize and present these complex devices. The digitized objects can be used to create further reconstructions of possible usage, not only to enable rotating and zooming in on them, for example [70].

Like the bibliographic description of an old map, the metadata description of a globe should be improved from the simplest to the most complex form of description. Metadata not only enable subsequent retrieval by the user, but in the event of damage or even loss, they can provide very accurate information that can be used to reconstruct or trace the given collection item.



Globes are usually described individually, but there are cases where they are described as a set or pair. Indeed, old globes were usually made in pairs, that is, as terrestrial and celestial globes [71]. Therefore, it is advisable to try to track down information about the second, paired globe in information sources and mention it at least in the metadata description, if there is no online availability of the paired globe. According to the available information, J. Jüttner did not make a star globe as the second in the pair. Therefore, this matter need not be given further attention.

In addition to basic descriptive information about the globe, such as the title, subtitle, author, secondary authors, scale (star globes do not have scales), place, publisher and the year of publication, the physical description fields (diameter, circumference, base) are much richer for globes than for conventional maps. This is due to the different materials the globes are made of. The accuracy and quality of metadata are very important, especially in the physical description, because the researcher of a digitized product does not have access to the original physical product. Important is the exact size, and the globe circumference from which both the diameter and the scale are derived.

From the 15th to the early 19th century, intaglio copperplate engraving techniques were used in cartographic production. These techniques involve making indents or incisions into a metal plate surface (most often copper) which hold the ink when ink is applied to handmade paper. The quality of the printing plate determined the quality and even distribution of the printed ink. The quality of the print was also influenced by the intensity of the paper wetting, the ink density and smear, as well as the smooth passing of the print through the intaglio press. The scale and dimensions of the original globe map may therefore vary from source to source, as may the dimensions of the gores, depending on the time and method of obtaining the relevant data and the shrinkage of the handmade paper for a particular map. Similarly, the plaster base, the hemispheres, were handmade, and this could also cause differences in the diameter of the base sphere. Therefore, it will be very useful in the future to compare similar specimens of the same globe. This could shed light on what variations can occur in handmade globes. Further interventions by restorers, especially wet process cleaning, can lead to changes in the paper or in individual gore joints. It is therefore a good idea to take these into account.

As far as further processing is concerned, the globe gores were cut out by hand, so they could also have been different sizes before gluing. They were glued on a plaster or paper base material by hand. A high-quality globe product was characterized by the precise connection of the individual globe gores in the map image as well as in the description of geographical names. In inaccurate products, the globe gores were glued sloppily or did not connect in some parts. The question is whether to make (or were made) corrections of these manufacturing errors during digitization, when the segments can be accurately connected.

Information on the size of the base, and its height below the globe, should also be accurate. It is equally important to know whether the globe is furnished with a meridian semicircle or circle, how it is divided into gores and whether it has an hour circle, compass or calendarium. When digitizing, the meridian circle as well as the hour circle are often removed from the sphere or digitally eliminated. It is also appropriate to ask how to incorporate these parts into the digital presentation of the globe. Whether to settle for a photograph, a description or whether to try to combine them into one object remains an issue.

If possible, the map legend should be detailed in the digitized object's metadata. We can also expand and add information to the note fields. These include characteristic features of decoration, such as portraits, scenes, allegories, parerga and cartouches. It is possible to add literature references that cite the source of studies on the globe or the existence of the second globe to the pair. To describe in detail the method of manufacturing and the material, you may pay detailed attention to the content and write down interesting toponyms or factual information that is described on the globe. The note fields also include information on restoration efforts, repairs and changes to the globe in terms of connections of paper gores, color, material or replica stands. It is also a good idea to include the history

of ownership and provenance of the globe, if known. Additional notes should be made regarding language, edition, version, reprint, etc. A lot of other information can be drawn from supplementary documents such as the cover, information manuals, etc. A note on a defective specimen informs about the physical condition of the globe specimen, especially its damage.

The user should be knowledgeable of what type of globe they have access to. The objects are classified by: displayed object (terrestrial globes, planet globes, star globes), purpose (school, decorative, etc.), content (geographic and thematic), method of execution (smooth, embossed, luminous, duplex globes), induction globes (teaching aid without map content), free globes (have no axis and sit in a bowl), pneumatic (inflatable), processing technology (glued, injection-molded) or scale. So far, only celestial, terrestrial and embossed globes have been used for digitization purposes.

It is essential to always describe changes in the document history caused by restoration, preferably with pictorial documentation, original damage, various crooked paper gluing, inaccurate connections of the geographical names descriptions that have been corrected, different sizes or changes in the printing paper or other printing and manufacturing errors.

The physical condition or unique nature of a work may be crucial factors to be considered, as it may not be feasible to regularly lend out such works to the public due to security reasons or other restrictions imposed by restorers.

Many map collections are unable to describe their holdings for financial reasons. This is especially true about large archival or museum collections. Therefore, attempts have been made to digitize and display the globes owned by such institutions with minimum metadata, as has been performed, for example, in the Virtual Map Collection [19]. Although metadata are clearly highly beneficial for all digital representations as described above, in these special cases, even displaying a globe on the Internet with minimum descriptive metadata seems to be highly beneficial as well.

By virtue of such accessibility, the work has been recorded at a certain point of time, and thus documented. According to the depth of their interest and knowledge, the researchers can verify and complete the description of the work. If the work was to be lost or damaged in the future, there is a real chance of making a copy or at least creating a detailed description of it. Then, this can make it much easier for the police or the original owner to locate the work.

The method of digitization and visualization described above was tested on the antique Jüttner globe. There are other specimens of this globe in the Czech Republic. In the future, it would therefore be useful to find out about their physical condition and compare them physically. Furthermore, an attempt should be made to digitally document and compare them.

The suitability of SfM-MVS photogrammetry for the digitization and visualization of old globes was demonstrated. The method is simple and there is no need for expensive specialized equipment or software such as laser scanners or expensive metric cameras.

The globes can be digitized on site and do not have to be transported to a specially designed facility. The method is contactless, posing no threat of damage to rare old globes. Photographing can be performed with digital cameras now commonly available and boasting sufficient resolution to capture even the smallest details on the surface. Any number of images can be recorded and processed. Image acquisition is relatively quick compared to the computer conversion of data into a 3D model.

The relatively high processing power required of the computer used for processing the images appears to be a disadvantage of this method. The method cannot be applied in a universal way with the same setup and implementation. It always depends on the size of the object to be digitized, the possibility of handling the object and the site of the imaging. The lighting of the photographed scene was a serious problem. In the case of smaller globes, the use of a diffusion tent to improve the properties of the light can be useful. This is one of the reasons why all images had to undergo additional editing. The quality of the final textured model depends on the quality of the images. The quality of



the camera used is a closely related factor. A significant problem with cheaper cameras is lens distortion, which affects the geometric accuracy of the model. Every camera must be calibrated before use.

The digital 3D model of the Jüttner's globe was made available on the web using the Cesium JavaScript library. The advantage of this solution is the possibility to alter the source code and modify the visualization parameters of the globe. The solution makes full use of web technologies, and unlike purely software-based solutions, it does not require any software installation, only a web browser. Another advantage is the easy implementation of the model of a web browser. A common disadvantage of the internet presentations discussed here is the user's dependence on an internet connection.

The problem with making this globe available online was the considerable size of the resulting 14 MB glb format model. This resulted in the lengthy loading time of the model. This problem could have been eliminated by using image pyramids, which would have increased the speed of image data processing.

The tests performed showed the effect of using different web browsers on the speed of loading the 3D model and the entire website. They showed how quickly users can view content and interact. The resulting values are dependent on the speed of the internet connection and the performance of the PC, and are therefore not absolute. However, the speed of different browsers under the same conditions can be compared with each other. From the point of view of loading the model itself (Domcontentloaded and Load), Firefox emerged as the fastest browser. In terms of loading the entire website, the test identified MS Edge (1.000 s) and Google Chrome (1.057 s) as the fastest browsers.

When making globes available on the Internet, it is always important to respect the copyright and property rights associated with the use of the data in accordance with the law and licensing terms. However, old globes, published before 1850, are not affected by copyright restrictions.

## 5. Conclusions

The chosen method is universally suitable, but it is essential to adapt it to the selected globe. The size of the globe and the ease of manual handling of the object must be considered and the right camera chosen accordingly. However, creating the images is the most important step, as their quality determines the quality of the final model.

The proposed methodology of digitization and accessibility was verified by practice on the globe by J. Jüttner and originated from the first half of the 19th century. Another valuable collection item is now available to researchers 24 h a day. It can be distributed in a virtual environment to users who do not have any specialized software installed on their computers or mobile devices.

This piece of cartographic heritage is no longer exposed to changes in light, climate or temperature. Therefore, its lifetime can be substantially extended and the likelihood of preserving such a precious exhibit for future generations is increased.

The employees of the Map Collection of the Faculty of Science of Charles University will be inspired by this good practice when creating the new Virtual Globe Collection. Further research into user requirements is planned, taking into account the excellent results achieved via the User-Centered Design method; see, for example, the team creating the Virtual Atlas of Canada [61]. The authors plan to examine how this new model is used by both experts and non-experts.

This method is particularly suitable for raising awareness about collection exhibits and aiding the work of curators and restorers. Virtual presentation is also widely used in the field of cartography. In the future, the focus will be on further developing annotations with spatial information, i.e., the globes will be georeferenced. The user will be able to easily compare the quality of the old and new globe maps.

**Supplementary Materials:** Virtual Jüttner's globe is available online on the website [http://www.mapovasbirka.cz/globy/english/index\\_eng.html](http://www.mapovasbirka.cz/globy/english/index_eng.html).

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## Appendix A

**Table A1.** Example of a globe metadata record in MARC21 format. Source: Map Collection of the Faculty of Science, Charles University.

Tag	Value
LDR	02546nem a2200433 i 4500
001	990015521830106986
003	CZ-PrCU
005	20230130172719.0
007	dc#cpz
008	130218s1839 au d 0 ger d
034	1_ 1a a 1b 21000000 1d W1800000 1e E1800000 1f N0900000 1g S0900000
035_	a (CZ-PrCU)001552183
035_	a (CZ-PrCU)001552183CKS01-Aleph
040_	a ABD065 1b cze 1c ABD065 1e rda
072_7	a 913 1x Regionální geografie 12 Konspekt 19 7
072_7	a 912 1x Mapy. Atlasy. Glóby 12 Konspekt 19 7
080_	a 913:912.643 1x (100) 12 MRF
1001_	a Jüttner, Josef, 1d 1775-1848 17 jk01052284 14 ctg 14 pbl
245_10	a Erdkugel / 1c von 2 Wiener Schuh im Durchmesser nach den neuesten geographischen Bestimmungen entworfen und herausgegeben von Joseph Jüttner Oberstlieutenant im Kais. Königl. Bombardier Corps; in Kupfer gestochen von Bernhard Bitter und Joh. David
255_	a Scale 1:20,050,000 1c (W 180°00'00"—E 180°00'00"/N 90°00'00"—S 90°00'00")
264_1	a Zu Wien: 1b Joseph Jüttner, 1c 1839
300_	a 1 globe: 1b colored copper engraving, plaster covered with paper, on a wooden tripod, a metal horizontal circle with an engraved scale, a vertical wooden circle with a calendar and zodiac signs; 1c diameter 63.5 cm
336_	a cartographic image 1b cri 12 rdacontent
337_	a unmediated 1b n 12 rdamedia
338_	a object 1b nr 12 rdacarrier
500_	a The Prime Meridian passes through the Canary Islands
500_	a Globe circumference 199.5 cm, height from the original base pad to the pad of the copper meridian circle 41.8 cm
583_	a Restored in 2016; 1h RNDr. Miroslav Široký, CSc.; 15 CZ-PrUPM
590_	a Before restoration, the wooden circle was cracked, the coloring scraped off in many places, the globe tilted to one side 15 CZ-PrUPM
650 07	a world geography 17 ph120523 12 czenas
651_7	a countries of the world 17 ge131523 12 czenas
655_7	a terrestrial globes 17 fd796644 12 czenas
700 1_	a Bitter, Bernhard 14 egr
700 1_	a David, Johann, 1d active in the 19th century 17 jx20071127032 14 egr
856 41	u <a href="http://www.mapovasbirka.cz/globy/gallery/g79.html">http://www.mapovasbirka.cz/globy/gallery/g79.html</a> 1 Digitized document
910_	a ABD065
988_	a GEOUK
997_	a MP
998_	a 20140407

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