

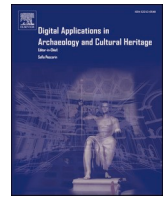


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Virtual scientific expedition for 3D scanning of museum artifacts in the COVID-19 period – The methodology and case study

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ABSTRACT

The COVID-19 pandemic has changed the way of working and living around the entire world. Unfortunately its influence on actions during scientific expeditions has to be evaluated as negative. Restrictions vastly limiting ability to travel around the world have frozen the execution of many institutional projects and initiatives, which has affected the cultural heritage domain as well. This article presents a methodology of temporarily avoiding travel restrictions by organizing a virtual scientific expedition. The 3D Silk Road project, and its modification enforced by the pandemic situation, is used as a case study. The authors describe: (1) the methodology of organizing virtual scientific expeditions to 3D scan objects of cultural heritage, (2) the methodology implementation, and (3) its results - a virtual micro-exhibition of 3D scanned works by Haydar Boturov, a clay sculptor from Uzbekistan. The methodology was proven successful in practice and might be used in other projects affected by severe travel restrictions between countries.

1. Introduction

The Department of Computer Science at the Lublin University of Technology (LUT), Poland, started its cooperation with the Samarkand State University (SamsU), Uzbekistan, in 2015. First, the parties communicated remotely by the means of the Internet, which further evolved into full personal contacts and regular scientific expeditions. After many years of direct contacts and meetings in Poland and Uzbekistan, the world-wide COVID-19 pandemic and severe travel restrictions have limited the cooperation to online (i.e. remote) activities again (United Nations, 2020).

The cooperation between LUT and SamsU was interdisciplinary in its character from the beginning. The LUT team's core competences are focused around reverse engineering, 3D modelling, and rapid prototyping. From the other side, the SamsU team is composed of people interested in broadly understood cultural heritage, working for the university or museums of Samarkand. The synergy of individual and team competences allowed for mutual initiatives in the fields like: 3D scanning of museum artifacts, 3D scanning of architectural objects, utilizing 3D models to support conservatory works, or moving digital

objects to virtual museums and virtual reality.

During 2015–2016 (the phase of distant contacts) LUT and SamsU cooperated, by means of remote technologies, to define a roadmap of common activities and accomplish first mutual projects (Miłosz et al., 2015; Montusiewicz et al., 2015, 2016). The next phase in 2017–2019 was based on direct contacts among team members from partnering countries. It was possible among others thanks to the three subsequent scientific expeditions to the Central Asia countries organized by the LUT team. The formula of the expeditions included practical activities, i.e. 3D scanning, as well as research and dissemination activities, i.e. seminars delivered in various scientific institutions (Miłosz et al., 2020c). In addition, in 2018–2019 the scope of exploration was extended beyond Uzbekistan, namely to neighboring countries of Kazakhstan and Kyrgyzstan.

The participants of the expeditions took with them specialized equipment for 3D scanning, data processing and documenting activities: terrestrial laser scanner (FARO Focus X 330), 3D structured-light scanners (Artec Spider, Artec Eva), digital camera with additional lenses (Nikon D5300), two laptops (Intel i7 CPU, 32 GB RAM, GeForce GTX 980 8 GB graphics card). Software used on-site included Faro Scene,

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Cloud Compare and Artec Studio Professional. Software for post-processing included Blender and MeshLab. With these, it was possible to make scans of nearly 100 museum artifacts and 12 large architectural objects. Gathered data was used for the purpose of research methodologies verification and preparation of new articles (Montusiewicz et al., 2018, 2019; Miłosz et al., 2020a, 2020b; Żyła et al., 2020). During the scientific seminars, both the joint achievements and opportunities for further cooperation were presented.

The next phase of cooperation was preparation of two editions, in 2018 and 2019, of the scientific conference called “Information Technology in Cultural Heritage Management (IT-CHM)”. The first one (IT-CHM/2018) took place at LUT (Poland), and the second one (IT-CHM/2019) in an important historical place, i.e. in the Ulugh Beg Madrasa at the Registan Ensemble in Samarkand (Uzbekistan).

Acquiring a joint research project from the Polish National Agency for Academic Exchange (NAWA) titled “3D DIGITAL SILK ROAD” opened up completely new perspectives for further activities, especially thanks to the four partnering universities originating from Uzbekistan: National University of Uzbekistan (Tashkent), Samarkand State University (Samarkand), Chirchik State Pedagogical Institute (Chirchik) and Urgench State University (Urgench). Shortly after the project started, just after the kick-off meeting of the project was organized at LUT, the world froze due to the COVID-19 pandemic.

The movement of people around the world was severely limited. Most of scientific expeditions could not be carried out due to the ban on entry to various countries or very restrictive quarantine conditions. Fortunately, the transport of goods around the world has not been stopped, so they could be sent between different countries. Thanks to the Internet, especially videoconferencing and large files transfer, the possibility of remote work was maintained. These elements contributed to the chances of carrying out virtual expeditions for the purpose of 3D scanning of museum objects in Uzbekistan by scientists from LUT.

This article presents the background and methodology of organizing a virtual scientific expedition on the example of 3D scanning of artifacts in a Samarkand museum. The methodology makes use of technical and organizational possibilities available in the COVID-19 period in order to aid execution of planned project activities. The case study of the virtual expedition implementation and its results, that are provided in the article, can be used by other research teams that are in a similar situation with their projects.

2. 3D scanning technology

Development of 3D computer technologies, in terms of methods, devices and software, allows for a conscious choice of solutions, that will be used to 3D scan resources of material cultural heritage (Owda et al., 2018; González and Valls, 2020; Bieda et al., 2020). Modern methods of digitization can generally be sub-divided into passive and active ones (Ulguim, 2017; Tobiasz et al., 2019).

In the case of passive methods, a device does not emit a beam of energy from its own source, but sensors of the device capture information that comes from an object after reflecting energy originating from natural sources (e.g. from the sun) or emitting an object’s own energy (e.g. thermal energy). The most common solutions used so far in the area of cultural heritage are photogrammetry (Sporleder, 2016; Klapa et al., 2017) and Structure from Motion (SfM) (Horn et al., 2017; Bianco et al., 2018; Reljić et al., 2019) (they are not fully distinguished in many publications). In general, a 3D model is composed of a series of many photographs, that were taken in such a way to ensure a very large coverage of the same surface area on the neighboring photographs, reaching even 80%. Even for small objects, a very large number of photographs is required, ranging from 80 to 130 (Ulguim, 2017).

As for active methods, a device emits a beam of energy from its own source. This group includes laser scanners, that currently work most often as ground-based devices (TLS - Terrestrial Laser Scanner) (Wei et al., 2019; Miłosz et al., 2020a; Factum Arte, 2021). Laser scanners that

are hand-operated are available as well. Another group are devices operating in the Structured Light Technology (SLS); these are most often hand-operated (Kersten et al., 2018; Montusiewicz et al., 2019; Żyła et al., 2021). Nevertheless some structured light scanners are intended to be mounted on a tripod during operation and, after appropriate calibration, have to be left untouched (Smarttech, 2021). Objects to be digitized are placed then on a special rotating table, that is controlled by a scanner software and moved step by step by electric motors.

SLS scanners project a light pattern, most often fringes of different and additionally time-varying widths, onto a digitized object. It allows to accurately capture the geometric shape of the scanned object’s surface. Several cameras are built into these devices, as well as detectors that calculate the distance of surface points that are in range. Thanks to this, the object transferred to the digital world has its real dimensions. RangeVision NEO (RangeVision, 2021), that was used during the virtual expedition described in the article, is one of SLS scanners. Fig. 1 shows the scanner under operation, and Fig. 2 shows the view of a scanned object.

3. 3D Silk Road project

The joint research project granted by the Polish National Agency for Academic Exchange (NAWA) and titled “3D DIGITAL SILK ROAD”, introduced in section 1, was virtually stopped due to the COVID-19 pandemic. The core activities of the project had their origin in the on-site expeditions aimed at 3D scanning of Central Asian cultural heritage monuments (small museum artifacts and huge architectural objects).

Thankfully the project financing institution (NAWA), as well as the project contractors, were aware of and understood the threats to the project posed by the COVID-19 pandemic. The project received a green light for modifications oriented on, among others, forced virtualization (Miłosz and Miłosz, 2020) of selected tasks by means of information and communication technologies. Even changes in the scope of selected tasks became possible, while maintaining compliance with the main objectives of the project.

The following tasks were originally planned in the “3D DIGITAL SILK ROAD” project:

- organization of 4 research expeditions to 4 cities of Uzbekistan for the purpose of 3D scanning of cultural monuments,



Fig. 1. 3D digitization of an object with a RangeVision NEO scanner: (a) Scanner; (b) Tripod; (c) Rotating table; (d) Laptop with software; (e) Scanned object.



Fig. 2. Scanned object illuminated by structured light.

- preparation of 3D models and panoramas based on the obtained 3D scans and placing them on an internet portal,
- organization of 2 international conferences (in Poland and Uzbekistan),
- organization of 2 photographic exhibitions,
- conducting specialist courses on the application of 3D technology in museology,
- dissemination of the project results on a website, on conferences, in articles, and in a monograph.

Due to the COVID-19 outbreak, scientific-exploratory expeditions to Uzbekistan to 3D scan cultural monuments became impossible. What came up as a solution was the idea of a Virtual Scientific Expedition (VSE), which the authors define as the implementation of regular expedition activities by means of remote technologies. The activities are adjusted to capabilities of the remote technologies used, while maintaining compliance with the original objectives of the expedition. In case of LUT and SamSU the VSE looked as follows:

1. SamSU staff performed 3D scanning of objects under the remote supervision of LUT staff. SamSU staff chose the most suitable collection of objects for scanning and provided historical description of the collection.
2. Results of scanning were sent through the Internet to LUT for post-processing and preparation to be disseminated in a digital form.

The following issues were identified as the main obstacles when organizing the VSE: (1) the lack of 3D scanning equipment at SamSU, and (2) insufficient/missing 3D scanning skills among the museums and SamSU staff. Thankfully the progress in modern technology and development of smart societies provided tools to overcome the above-mentioned issues, to mention the ability:

- to ship 3D scanning equipment from Poland to Uzbekistan,
- to conduct remote training of SamSU staff on the shipped equipment and software usage,
- to conduct 3D scanning of cultural heritage objects by trained SamSU staff, under the remote supervision of specialists from LUT,
- to send large amounts of data from SamSU to LUT via cloud services,
- to perform data post-processing at LUT, by local specialists, for the purpose of preparing and publishing virtual exhibitions on the “3D

Digital Silk Road” portal (Silkroad3D.com, 2021a), being one of the project results.

The project managers were successfully able to address all technological and organizational challenges to avert the threats to the project realization. It was possible to introduce necessary tasks modifications and exploit technology capabilities, that led to the successful implementation of a virtual expedition (Miłosz and Miłosz, 2020).

4. Methodology of a virtual scientific expedition preparation and its implementation

The methodology of preparing and implementing a VSE to Samarkand was developed on the basis of two assumptions: freight traffic in the world is possible and it is possible for LUT scientists to work remotely with museum employees in Samarkand, who are supported by computer scientists from SamSU. Both assumptions during COVID-19 pandemic could be met. The main idea behind the methodology was that scanning during VSE would be performed by SamSU employees using a 3D scanner sent to SamSU, and data processing (post-processing) would be carried out by LUT employees using hardware and software available at LUT.

The developed methodology consists of three stages, implemented both by LUT and SamSU staff (Fig. 3):

1. VSE preparation.
2. VSE implementation.
3. Final stage.

Stage 1 - **VSE preparation** - it consists of the following activities (Fig. 3):

- **Tasks planning.** During this activity, tasks to be performed, their parameters (including costs), manner of implementation and schedule were planned. A significant problem here was finding a way to deliver a 3D scanner to Uzbekistan (i.e. a courier company) and the fulfillment of quite complicated procedures on the Polish and, especially, Uzbek side. The scanner was also selected – it was a Rangevision NEO scanner. The choice of this scanner was justified by its low cost and significant automation of the scanning process. The latter fact was important due to the lack of experience of SamSU employees in this type of work. A significant factor, considering a relatively low English proficiency among SamSU employees, was the availability of a Russian-language user manual and software interface.
- **Training preparation.** During this activity the training implementation was prepared (i.e. training plan, methods to be used during the remote training, hardware and software requirements on the Polish and Uzbek side, personnel to be trained, etc.).
- **Selection of artifacts.** SamSU staff selected museum artifacts for the purpose of training and the VSE. The selection was made taking into account data on the working area of the 3D scanner and the scientific objectives of VSE. A collection of ceramic dishes by a famous creator from the turn of the century, Haydar Boturov, and the Uzbek national headgear, “Tibiteyka”, were chosen. In addition, vessels with different surface textures were also selected in order to use them during training to determine the limits of the 3D scanner’s capabilities.

Stage 2 - **VSE implementation** - it consists of the following activities (Fig. 3):

- **Scanner shipping.** The 3D scanner was shipped to Uzbekistan using one of the global courier companies. After more than a week, the scanner, which was sent from Lublin, via Frankfurt and Dubai, reached Tashkent, and from there it was delivered to Samarkand.

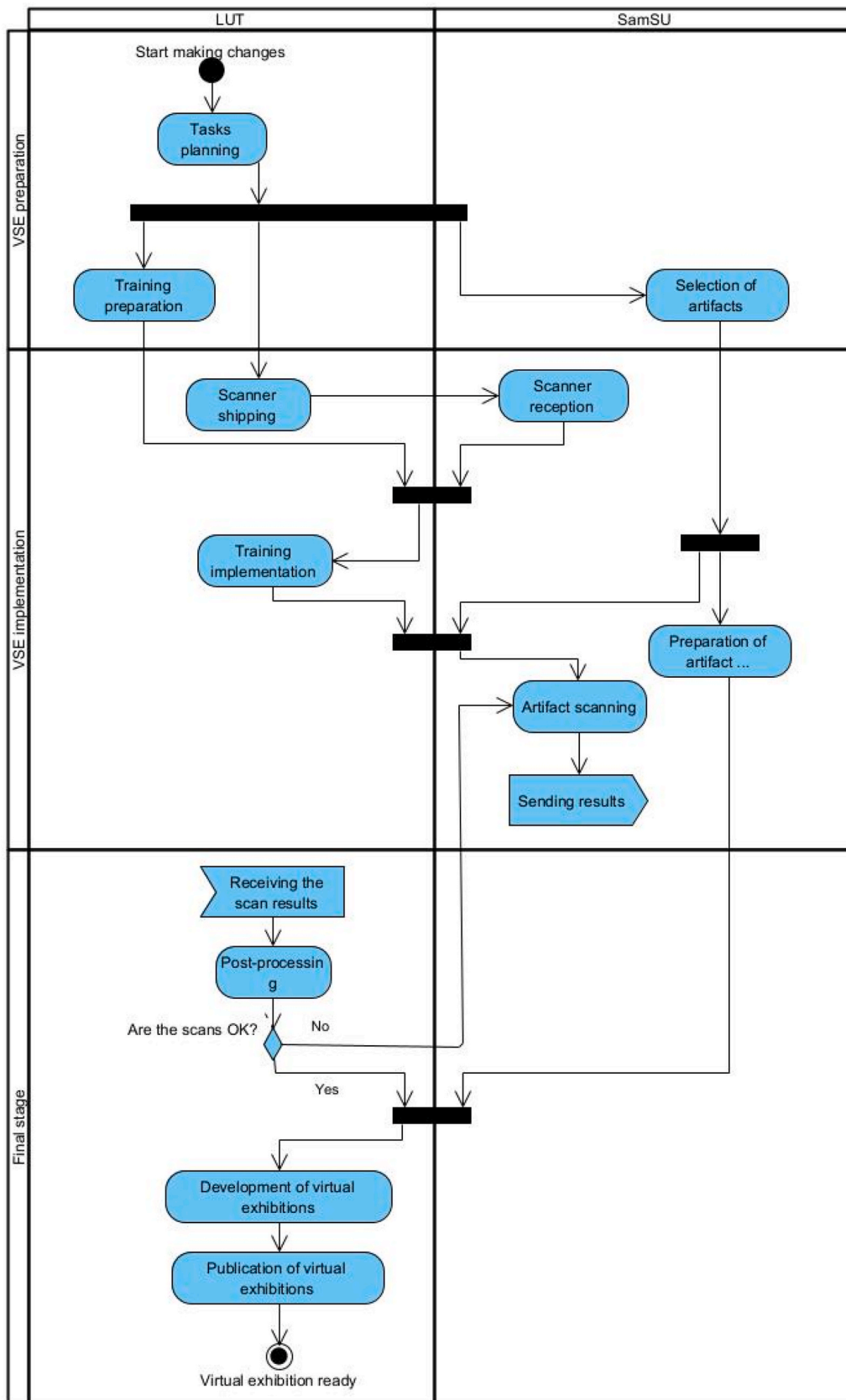


Fig. 3. Schema of the developed methodology of preparing and implementing a virtual scientific expedition.

- **Scanner reception.** The 3D scanner found its way into the hands of SamSU employees with some delays due to bureaucratic problems, as well as the fact that such an operation was performed for the first time in the history of SamSU.
- **Training implementation.** The training was conducted in the remote videoconference mode using the Zoom platform.
- **Preparation of artifacts descriptions.** A team of museologists, SamSU employees, prepared descriptions of the scanned artifacts, i.e. name of an artifact, historical background, author, dimensions, material, date of creation, photographs.
- **Artifacts scanning.** This activity can be perceived as the main part of the VSE. SamSU employees scanned museum artifacts under the remote supervision of LUT employees. Scan results were initially remotely checked for quality and archived.
- **Sending results.** The scan results, after compression, were sent by the SamSU team to one of the cloud datastore services.

Stage 3 - **Final stage** - it consists of the following activities (Fig. 3):

- **Receiving the scan results.** The LUT team downloaded data (the scan results) from one of the cloud datastore services.
- **Post-processing.** Processing of scan data by combining point clouds, creating a mesh model and target models in order to present the results on the Internet as a virtual exhibition. This kind of processing requires the use of specific software, hardware and skills in the area of computer graphics and 3D modeling, thus it was done by specialists from LUT.
- **Development of virtual exhibitions.** 3D models of the scanned artifacts and their descriptions were used to develop virtual thematic exhibitions. It required the use of specific software, hardware and skills in the area of computer graphics and virtual exhibitions development, thus it was done by specialists from LUT.
- **Publication of virtual exhibitions.** The virtual thematic exhibitions were published online on the “3D Digital Silk Road” portal (Silkroad3D.com, 2021a), which is developed as a part of the NAWA project called “3D DIGITAL SILK ROAD”.

The methodology presented in Fig. 3 was used to implement the “Virtual Scientific Expedition of LUT to the Silk Road – Samarkand 2021 (VSE-SR’21)” in the first half of 2021.

Before VSE-SR’21 SamSU staff was trained by LUT staff, how to organize a scanning site and use a 3D scanner. During the training, the 3D scanner calibration process turned out to be a significant problem.

Unfortunately, it was necessary to change a large part of the default scanner software settings and calibrate the scanner using special plates (Fig. 4). The calibration process was mastered by SamSU employees after several unsuccessful repetitions.

VSE-SR’21 was implemented as a series of 3–4 h sessions, when the museum artifacts selected beforehand were 3D scanned. The process of scanning museum artifacts was carried out automatically by the software and hardware (including the rotating table) of the scanner. It was supervised remotely by LUT employees (Fig. 5 and Fig. 6). In most cases, it ran smoothly for typical objects.

By default, the same computer was used at the same time for scanning and videocall by Zoom - to see the result of scanning (e.g. to evaluate its quality), and to see the interface of scanner software (e.g. to give hints what to do next). Separate computers were used only few times due to problems with quality of the Internet connection. LUT team, during the scanning sessions, did not remotely control the computer and scanning equipment in Uzbekistan, as it was not necessary. Both parties LUT and SamSU worked on the same equipment – the same 3D scanner model.

When it comes to effort and duration of activities, preparation of training activities during the stage 1 took 8 h of 1 LUT specialist’s work. Artifacts choice was done during 3 days - 2 collections were chosen. During the stage 2 the following goals were achieved: 3D scanner shipment, training implementation, and scanning of the chosen collections. Customs office procedures (unexpected fee occurred) and COVID-19-related issues caused delivery of the scanner to last about 1 month. Training lasted for 2 days, each time for 6 h. Two operators were trained by 1 LUT specialist accompanied by a translator. Scanning of the chosen collections was performed during 6 sessions, for 3–4 h each. Each of the sessions involved 3 persons from SamSU and 2 persons from LUT (1 specialist and 1 translator). The stage 3 goals were processing of the 3D scans obtained by digital means from SamSU and building the virtual exhibition showing the scanned objects. It took 2 h of a LUT specialist’s work to process each one of the 24 scans. Additional 10 h of a LUT specialist’s work was necessary to prepare the virtual exhibition.

The 3D scanner delivery in both directions (Poland - Uzbekistan and Uzbekistan - Poland) was performed by an external company, from where the scanner was obtained. The scanner underwent similar procedures traveling in both directions. The company handled the insurance and the shipping, striving for the highest profitability.

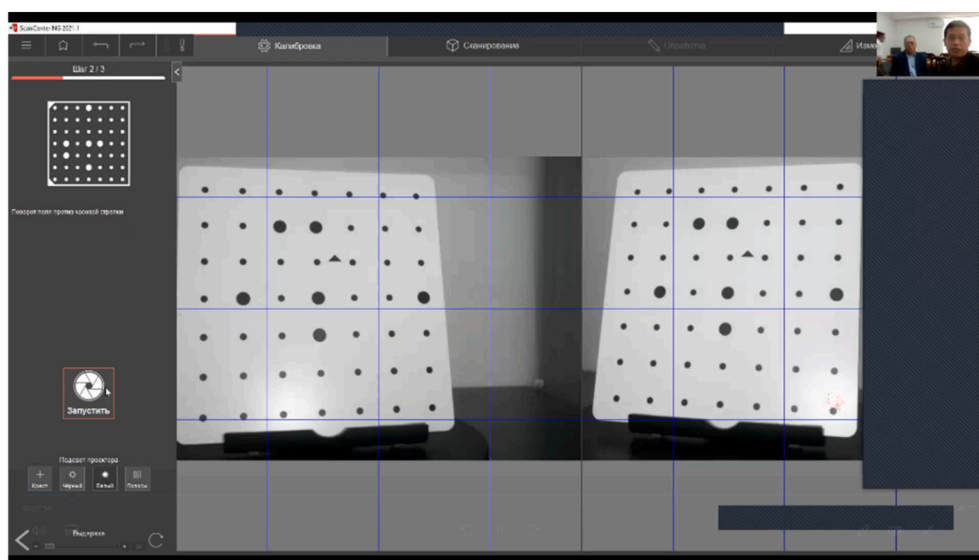


Fig. 4. Calibration process of the RangeVision NEO scanner.



Fig. 5. Scanning session of the “Elephant with jugs” supervised by LUT staff via the Zoom software.

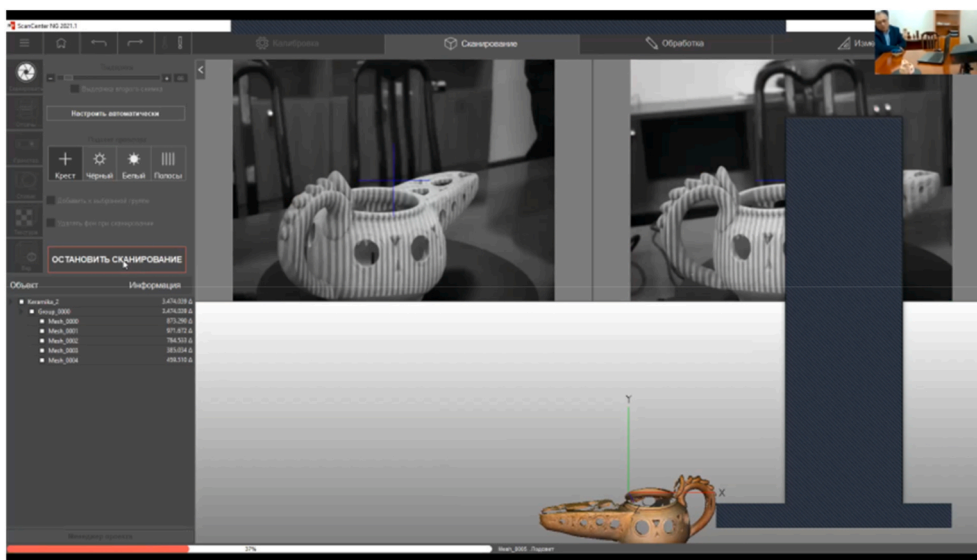


Fig. 6. Scanning session of the “Teal” supervised by LUT staff via the Zoom software.

5. Results of the virtual scientific expedition

One of the VSE-SR'21 goals was to create a virtual thematic exhibition of ceramic souvenirs made by the Samarkand clay artist Haydar Boturov between the 1970s and the beginning of the 21st century (Table 1).

Raw scans of ceramics, results of scanning each object, were saved under the same naming convention defined by both teams. Parameters of the data acquired during the scanning session (including data amount in GB) are shown in Table 2.

The acquired raw scans were compressed and transferred to LUT using the Google Drive service. Raw data of each object was processed by LUT employees to obtain a texturized mesh model. The upper limit of the scanner software for 3D model generation is 0.5 M faces. The maximum allowed number of faces was set up in each case. The overall effects summary is presented in Table 3. The authors evaluated the models and came to a consensus about the degree of the final quality of each model.

The resulting meshes of the objects 1, 3, 5, 6, 7, 8 and 9 were

considered to be of good quality, ready to be prepared for dissemination. The mesh of the object 2 contained several discontinuities that were too big to be automatically compensated. The main reason is the existence of numerous holes in the object, thus the 3D scanner was not able to mark all the vessel walls. The model can be either presented as is or returned for additional scans. The mesh of the object 4 could not be properly created because of too fragmented partial scans. The highly glossy surface of the object prevented the 3D scanner to properly recognize the object's surface. It is recommended to repeat the object scanning with more suitable settings. Successful results of the post-processing are shown in Fig. 7.

The obtained 3D models of ceramics (Fig. 7) were simplified (number of faces was decreased by 50%) and saved in a custom format suitable for presentation on the Internet. The models can be seen (among others) as “Clay sculptor Haydar Boturov’s works - 3D virtual mini-exhibition” (Silkroad3D.com, 2021b) which is available on the “3D Digital Silk Road” portal (Fig. 8).

Table 1
Description of the ceramics by Haydar Boturov that underwent 3D scanning (examples).








Object no	Description	Image
1	Ceramic souvenir “Elephant with jugs” from the series “Caravans of the Great Silk Road”. Approximate sizes: height 12 cm, width 15 cm. Made in 2001. Author: Haydar Boturov, clay.	
2	Ceramic souvenir “Teal” (olive lamp). Author: Haydar Boturov, clay. Approximate sizes: height 7 cm, width 16 cm. Made in 2001.	
3	Ceramic souvenir “Kuzacha 1” (jug). Author: Haydar Boturov, glazed clay. Approximate sizes: height 12 cm, width 8 cm. Made in 1973.	
4	Ceramic souvenir “Zom” (mug). Author: Haydar Boturov, glazed clay. Approximate sizes: height 15 cm, width 10 cm. Made in 1973.	
5	Ceramic souvenir “Kuzacha 2” (jug). Author: Haydar Boturov, glazed clay. Approximate sizes: height 8 cm, width 6 cm. Made in 1973.	
6	Ceramic souvenir “Guldon” (Flower vase). Author: Haydar Boturov, inside glazed clay. Approximate sizes: height - 29 cm, width - 14 cm. Made in 1998.	
7	Ceramic souvenir “Jug in the form of a bird”. Author: Haydar Boturov, clay. Approximate sizes: height - 25 cm, width - 14 cm.	

Table 1 (continued)




Object no	Description	Image
8	Ceramic souvenir “Savora” (On a donkey). Author: Haydar Boturov, clay. Approximate sizes: height - 16 cm, width - 11 cm. Made in 1998.	 
9	Ceramic souvenir “Azhdar” (Dragon). Author: Haydar Boturov, clay. Approximate sizes: height - 15 cm, width - 14 cm. Made in 1998.	

Table 2
Summary of the raw effects of the ceramics 3D scanning session.

Object no	Object name	Number of scan positions	Exact object cubature (depth x width x height) in cm	Data amount in GB
1	“Elephant with jugs”	3 × 12*	11.8 × 14.7 × 13.4	1.37
2	“Teal”	5 × 12	9.3 × 21.3 × 9.2	2.03
3	“Kuzacha 1”	4 × 12	7.9 × 8.1 × 13.0	1.89
4	“Zom”	5 × 12	15.8 × 9.3 × 15.1	2.02
5	“Kuzacha 2”	2 × 12	6.6 × 6.7 × 8.2	0.80
6	“Guldon”	6 × 12	12.9 × 13.6 × 28.7	1.10
7	“Jug in the form of a bird”	6 × 12	12.4 × 17.2 × 23.4	3.12
8	“Savora”	5 × 12	9.4 × 6.9 × 16.5	2.07
9	“Azhdar”	3 × 12	7.7 × 15.8 × 15.1	1.31

(*) Each automated scan on a rotating table produces 12 partial scans of an object.

6. Discussion

The proposed methodology for organizing virtual scientific expeditions proved to be successful - the museum staff had to deal with only the necessary minimum of technological issues related to the preparation of the 3D scanner and the scanning process itself. The possibility of using the rotary table for auto-calibration and scanning significantly simplified and accelerated the learning process.

Table 3
Summary of post-processing of the ceramics 3D scans.

Object no	Object name	Post processing time in min	Model quality
1	“Elephant with jugs”	75	good
2	“Teal”	85	acceptable
3	“Kuzacha 1”	57	good
4	“Zom”	240	inacceptable
5	“Kuzacha 2”	43	good
6	“Guldon”	73	good
7	“Jug in the form of a bird”	62	good
8	“Savora”	60	good
9	“Azhdar”	76	good

The quality and constancy of lighting at a scanning site (e.g. a museum room) significantly influence the scanning process. It is necessary to select a scanning site so that external factors (e.g. sunlight) do not interfere. Such site was selected once, and used in subsequent sessions. Both the training and scanning sessions took place in the same room and at the same time of a day, which assured similar scanning conditions and simplified the configuration of the 3D scanning process.

The capabilities of modern remote communication technologies turned out to be indispensable for the implementation of a virtual scientific expedition. The ability to observe both the image of the working area and the screen of the scanning application on an ongoing basis and

without significant delays allowed for the training similar to a personal show - the trainee performed the calibration and scanning task under the supervision of an expert, receiving ongoing comments and confirmation of correct actions.

The obtained results - raw 3D scans of series of objects turned out to be good enough to generate models of these objects and disseminate them on the Internet. The selection of exhibits resulting from the previous arrangements made it possible to prepare a 3D virtual mini-exhibition of Haydar Boturov’s works presented on the “3D Digital Silk Road” portal.

The 3D scanner software limited the complexity of 3D models to 0.5 M faces, thus the 3D models could not reach the level of details registered by the 3D scanner. The possibility of using additional software (without faces limitations), especially for the purpose of creating an exact digital copy of a heritage object, is yet to be explored.

At last, the final stage of the proposed methodology not always has to be devoted to creating a virtual exhibition. It could be adopted to address the needs of other purposes, like reconstruction, documentation, building virtual worlds, creating digital twins, etc.

7. Conclusions

The time of the global COVID-19 pandemic has resulted in many in situ research activities being completely stopped due to the inability of people to travel between countries. In this new situation, the concept of



Fig. 7. 3D models of successfully post-processed 3D scans of ceramics: (a) “Elephant with jugs”; (b) “Teal”; (c) “Kuzacha 1”; (d) “Kuzacha 2”; (e) “Guldon”; (f) “Jug in the form of a bird”; (g) “Savora”; (h) “Azhdar”. Descriptions of the original objects are presented in [Table 1](#).

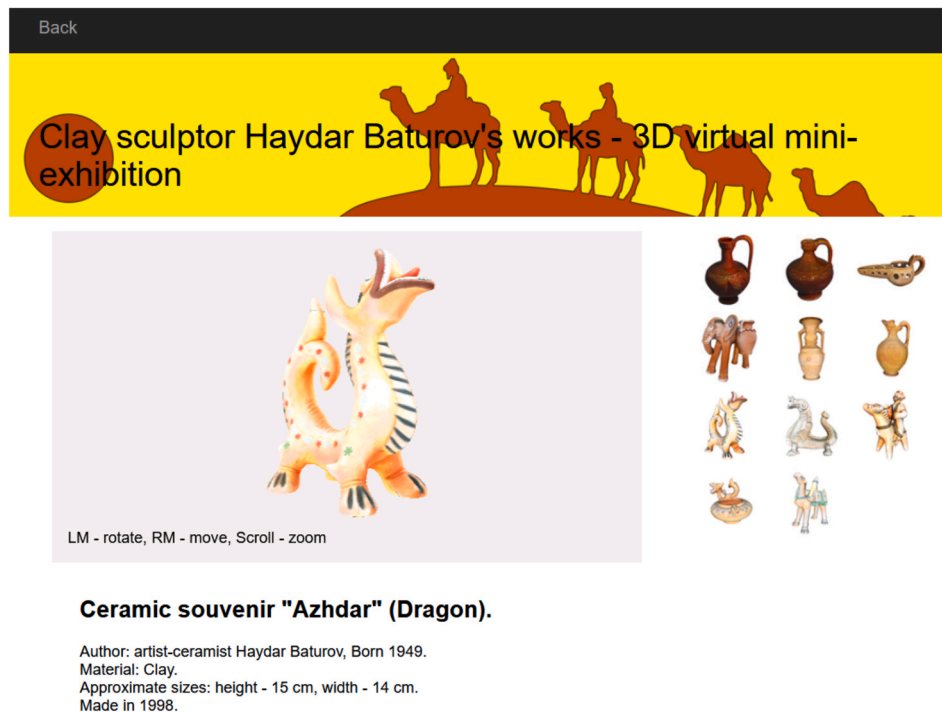


Fig. 8. The 3D virtual mini-exhibition on the "3D Digital Silk Road" portal (Silkroad3D.com, 2021b).

changing the previously binding paradigm of a scientific expedition arose, which stated that the necessary condition was the movement of people and equipment. The approach presented in the article changes the necessary condition - it is enough to move the equipment. In addition, this approach means that duration of the expedition can be long-term, continuous, or even permanent, and at the same time asynchronous.

Each well-prepared international cooperation has to be based on competent research teams - people who, apart from professional knowledge, are able to effectively engage in various non-standard activities. In this situation, knowledge of the people from SamSU team (Uzbekistan) had to be expanded with new IT and ICT-related competences. The activities of the LUT (Poland) team also required solving new organizational and logistic problems: renting a 3D scanner, sending it to partners in Uzbekistan, conducting a remote training on its operation.

The methodology of preparing and implementing virtual scientific expeditions, proposed in the article, was implemented during the VSE-SR'21 expedition, prepared as a part of the project activities that was granted by the Polish National Agency for Academic Exchange (NAWA). The obtained results, presented as a mini-exhibition on the "3D Digital Silk Road" portal (Silkroad3D.com, 2021b), prove that the developed methodology allows for (1) effective 3D scanning of museum objects of sizes compatible with the supplied equipment, (2) post-processing of the obtained data and (3) its dissemination in the virtual space. The implemented methodology can also be used in other projects of similar type and conditions.

CRediT authorship contribution statement

Marek Miłosz: Conceptualization, Methodology, Formal analysis, Investigation, Writing-original draft, Writing-review & editing, Supervision, Project administration. **Jerzy Montusiewicz:** Conceptualization, Validation, Formal analysis, Investigation, Writing-original draft, Supervision. **Jacek Kęsik:** Software, Validation, Investigation, Data curation, Writing-original draft, Visualization. **Kamil Żyła:** Software, Validation, Investigation, Data curation, Writing-original draft, Writing-review & editing, Visualization. **Elżbieta Miłosz:** Resources, Writing-

original draft, Visualization, Project administration, Funding acquisition. **Rahim Kayumov:** Validation, Investigation, Resources, Data curation, Writing-original draft. **Nodir Anvarov:** Software, Resources, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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