Article

The use of modern measurement methods in the inventory of endangered cultural heritage objects in Lviv

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Abstract: The article is devoted to the problem of documenting, visualising and inventorying cultural heritage objects using modern methods of measuring, storing and integrating large arrays of heterogeneous data. Several examples of documenting monuments in Lviv and its surroundings are presented. Various methods and technologies of data collection and processing of point clouds are applied and described, namely: the photogrammetric method in the study of an archaeological ground object using the Delta photogrammetric station, the method of terrestrial laser scanning and 3D modelling of monuments in the FaroScene program, the use of UAVs at low altitudes for documenting monuments, data processing, measurement and creation of dynamic virtual models in the AgiSoft PhotoScan program. The methodology for generating a virtual model of a monument from a group of images in ReCap Photo is presented. The article also describes the possibilities of documenting and archiving monuments documentation in graphic-attribute databases on the example of the developed information and reference system "Golden Horseshoe of Lviv Region" and a virtual tour in ArcGIS and Tourweaver.

Keywords: Modern Technologies; Cultural Heritage; Preservation; Safeguarding

1. Introduction

Cultural heritage is a set of spiritual and material values created throughout the history of humankind and inherited from previous generations, the result of people's spiritual and material activity. Objects of cultural heritage are original and unique tangible and intangible works of historical value that are protected by law [1]. Cultural and natural heritage sites arouse wonder and admiration among concerned people and tourists and are also objects of study and research in solving various scientific and applied problems. Cultural heritage sites exist in space, time and people's minds; they form the value of the environment and have scientific, cognitive and educational significance.

According to the expanded classification, tangible cultural heritage sites include unique above- and below-ground monuments: works of history, architecture, painting, monumental sculpture, archaeological elements and structures, urban ensembles, natural and landscape monuments, outstanding engineering and scientific structures, contents of libraries and museums that are of historical and cultural value and are the property of humankind [2].

Many reasons can destroy cultural heritage sites and lead to irreversible consequences and losses. The main threats to the existence and causes of destruction of historical, cultural and natural monuments include

- time and evolutionary changes (weathering of rocks, changes in daily and seasonal temperature regimes, geological movements of the earth's crust);
- natural disasters and cataclysms (earthquakes, volcanic eruptions, floods, fires, hurricanes, droughts, global climate change)
- wars, armed conflicts;
- anthropogenic impacts (vandalism, destruction as a result of industrial or private development);
- unnatural disasters.

For research, documentation and inventory of cultural heritage sites, a systematic and comprehensive approach is used, studying not one single object but considering it as an element of a single whole, in its interrelationship with the environment, in the spatial and temporal aspect of its formation and development. The capabilities of modern science and technology allow for the integration of various measurement methods and data storage in the databases of powerful spatial information systems.

The inventory of cultural heritage sites in Ukraine has become particularly important during the Russian aggression and the destruction of Ukrainian lands, cities and villages. During the war, the enemy destroyed hundreds of historical, cultural and natural monuments of national and regional significance.

Lviv is a significant ancient city in western Ukraine, an educational, scientific and tourist centre. In 1998, the historic centre of Lviv was included in the UNESCO World Heritage List. Many different monuments and architectural ensembles are protected by law and require comprehensive conservation, documentation, protection and promotion measures [2,3].

This article aims to describe and analyse the possibilities of using various methods and technologies for documenting and inventorying cultural heritage objects on the example of monuments in Lviv and its surroundings.

2. Materials and Methods

Modern digital methods and technologies for collecting and processing information can significantly expand documentation possibilities for the inventory of monuments. Nowadays, methods and technologies for documenting cultural and natural heritage sites are highly accurate and efficient For that purpose methods of 3D shapes measurements based on active and passive sensors are used [4–11], among others:

- close-range photogrammetry,
- terrestrial laser scanning (TLS)
- low-altitude surveys from unmanned aerial vehicles (UAV)
- radar survey
- thematic mapping
- computer programs for 3D modelling and rendering,
- GIS - technologies, data classification and coding, data visualisation
- organisation of registers, databases, and integration of graphic and attribute data.

Thanks to non-contact and non-destructive high-precision methods such as aerial surveys, radar or laser scanning, it is possible to obtain large amounts of data about an object in hard-to-reach places where it is dangerous, impossible or inadvisable for a person to be.

Among the remote sensing methods of cultural heritage sites, aerial photography from UAV is particularly relevant and commonly used in cultural heritage objects and site documentation [12,13]. This data makes it possible to generate point clouds and three-dimensional virtual models. One of the methods of modern inventory of cultural heritage sites is audio and video documentation. Graphical and attribute databases of spatial information systems allow the integrating and storing heterogeneous information about objects to visualise it on a map or in a digital terrain model.

Figure 1 shows the developed classification of methods and tools for documenting and inventorying cultural heritage sites.

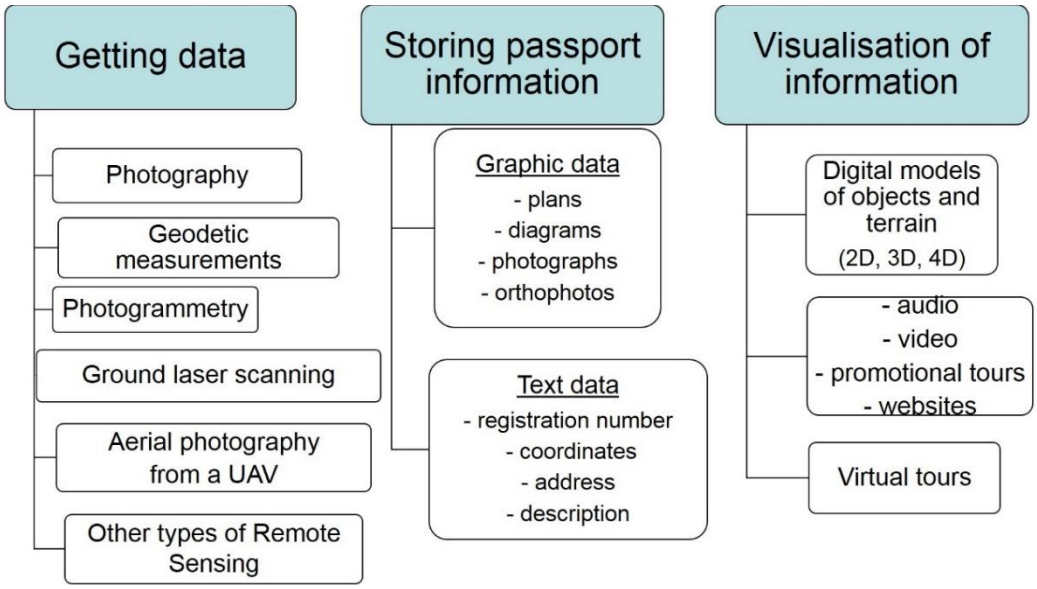


Figure. 1 General scheme of classification of methods and tools for documenting and inventorying cultural heritage sites

According to this scheme (Fig. 1), various historical and natural monuments in the city of Lviv and its environs were documented.

3. Results

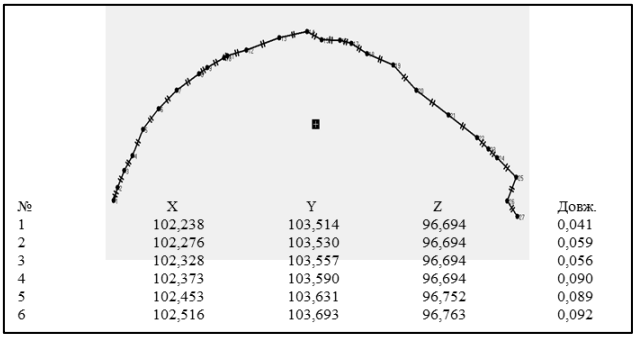
3.1. Documentation and modelling of urban archaeological objects utilising digital photogrammetry

Documentation of archaeological sites involves determining the geometrical shape of the object, functional and chronological analysis of the monument, graphical presentation (mapping) and description of the artefact's location [14]. Today's most widely used methods of measuring and documenting archaeological sites are geodetic, cartographic, photogrammetric, aerial photography and laser scanning. The intensive development and implementation of information technology have also affected archaeology. Modern methods of detecting, measuring, mapping and modelling archaeological sites using the latest digital technologies greatly facilitate the work of archaeologists and expand the range of tasks and research in this scientific field [15]. Processing of remote sensing data in software and application complexes allows obtaining highly accurate and visual results - orthoimages, photo plans supplemented with cartographic data, archaeological and topographic plans with attribute databases, atlases, panoramas, three-dimensional digital models of the object (with and without raster texture), virtual models, animation.

The object of our research is the ruins of a medieval building in the historic centre of Lviv, which belongs to urban archaeology, the purpose of which is to search for and study the historical layers of cities. In the course of the study of the archaeological site, a set of topographic surveys, digital photogrammetric surveys with a calibrated digital camera Canon EOS 350 and data processing by the photogrammetric method in stereo and mono modes using a digital photogrammetric station Delta were performed. A technological scheme for creating an orthophoto plan, a frontal plan and digital models of the object was developed and optimised, considering its texture's complexity. The frontal plans created on the Delta DSP in stereoscopic mode (Fig. 2) provide wide possibilities for measuring an archaeological site; namely: it is possible to measure the coordinates, angles, and lengths of any lines and points of interest to archaeologists for documentation or reconstruction of archaeological finds.

Figure. 2 The vector drawing integrated with the ortohimage

The two stereo pairs were used to perform spatial modelling of the long object with a complex surface, as well as to build 3D models of individual elements of the building that are of particular interest to archaeologists and to create their explications.



№	X	Y	Z	Довж.
1	102,238	103,514	96,694	0,041
2	102,276	103,530	96,694	0,059
3	102,328	103,557	96,694	0,056
4	102,373	103,590	96,694	0,090
5	102,453	103,631	96,752	0,089
6	102,516	103,693	96,763	0,092

Figure. 3 Stereo measurement of the arch contour and determination of point coordinates

According to the results of the accuracy assessment, the accuracy of the created frontal plan, 1:25 scale orthophoto plan and 3D models meets the requirements of archaeological work and mean square error for internal orientation was:

- 1 stereo pair: mx = 3 mm; my = 8 mm; mz = 4 mm
- 2 stereo pairs: mx = 3 mm; my = 7 mm; mz = 4 mm.

3.2. Spatial modelling, visualisation and mapping of the monument to Metropolitan Andrey Sheptytsky in Lviv

Modern non-destructive remote sensing methods and digital technologies for collecting and processing large data set significantly expand the possibilities of documenting cultural heritage

monuments. Laser scanning and unmanned aerial vehicles (UAVs) for large-scale mapping, 3D modelling, and video archiving are particularly relevant today.

Today, there are more than 70 monuments in Lviv, not including those in the Lychakiv Cemetery necropolis. Most of them are monuments of monumental art [16]. The monument to Metropolitan Andrey Sheptytsky in Lviv was chosen as the object of the study.

To document monumental structures, an integrated approach is proposed, which includes terrestrial laser scanning, aerial surveys from micro or mini UAVs, processing of aerial survey data and object modelling in specialised software, mapping and video archiving in a GIS database [17–19]. A technological scheme has been developed to implement this methodology.

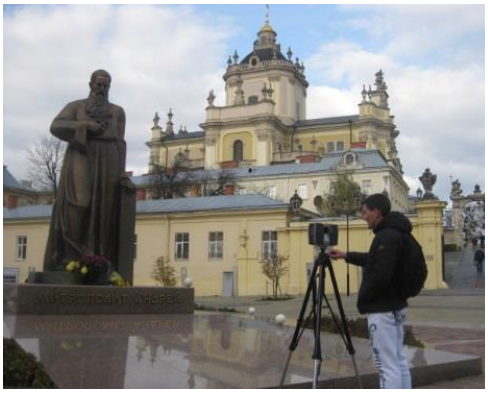


Figure. 4 Terrestrial laser scanning

Figure. 5 3D view of the object

Terrestrial laser scanning was performed with a Faro Focus3D scanner around the monument from 5 stations (Fig. 4). The ground control points were measured with a total-station Leica TCRP1201+R400. As a result of the relative register of scans, we can view the model in 3D mode, i.e. from different angles in three-dimensional space (Fig. 5).

In order to assess the quality of scan registration, the maximum and minimum values on check points were analysed- min = 1.6 mm, max = 6.7 mm

The results of the survey were registered points clouds with assigned RGB colours from the integrated camera to the TLS sensor (Fig. 6). Based on this data, it was possible in the FaroVideo module, to create a virtual dynamic model (Fig. 7) and save it in video format.

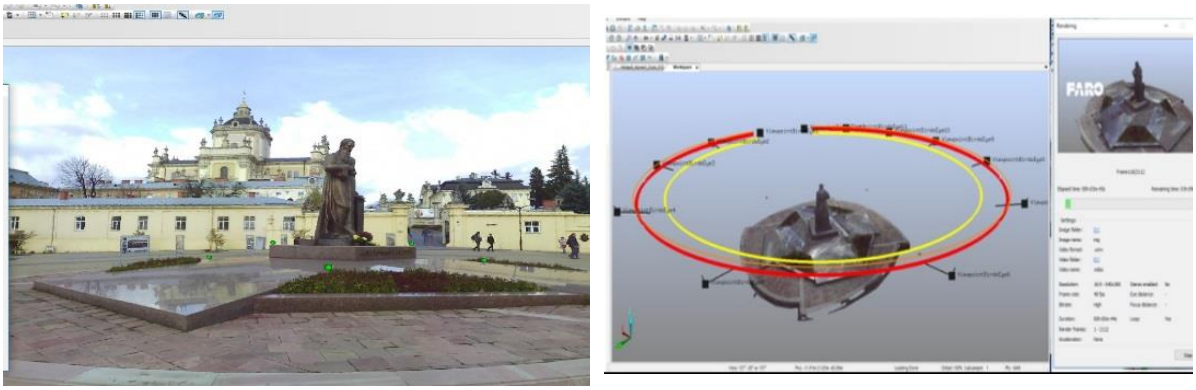


Figure. 6 Point cloud with the assigned real

RGB colours

Figure. 7 The example of generating a demo video file in FaroVideo software

The aerial survey was carried out with the DJI Phantom 3 Advanced UAV using remote control flight "by hand" around the monument at different heights, at the operator's choice. Image processing, visualisation, 3D object modelling, and video creation were carried out in the AgiSoft PhotoScan software environment. At first, we get a sparse and dense point cloud (Fig. 8), converted into a polygonal and then a textured virtual 3D model of the monument (Fig. 9).

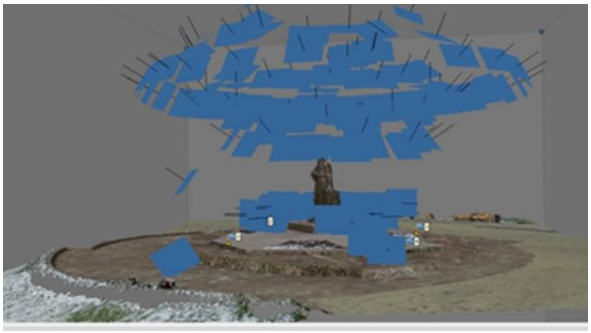


Figure. 8 The images distribution with the dense point cloud

Figure. 9 The example of the textured model of the investigated monument

The monument was mapped in the ArcGIS geographic information system, in which a class of point objects was created in the shapefile "Monuments", and a database was organised to store graphic and attribute information and photo and video materials about the monument. The data from the database can be visualised on the city map at the user's choice (Fig. 10).

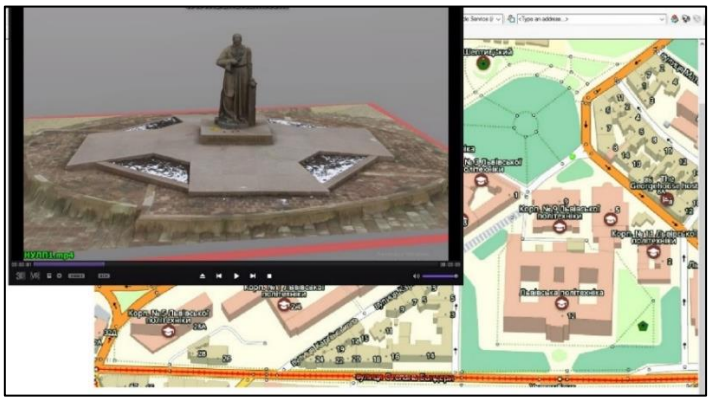


Figure. 10. The visualisation of the monument model with location on the city plan

3.3. Development of the information and reference GIS and virtual tour "Golden Horseshoe of Lviv Region"

Ukraine is rich in cultural and historical heritage sites, nature reserves and recreational areas that are attractive for tourists to explore and relax. Historical and cultural monuments can also be considered as tourist attractions. The main ways of documenting and visualising them are maps, booklets, digital landscape models, web applications, audio and video presentations, and virtual tours created using mapping systems and GIS technologies [20–23].

The input for the creation of the information and reference model "Golden Horseshoe of Lviv Region" is a topographic map of the Lviv region at a scale of 1:200,000, ArcGis GIS software, and information about places of interest, historical, cultural, and natural monuments. The map includes a tourist route that consists of the following settlements: Olesko, Pidhirtsi, Zolochiv,

Pidlysia, Havarechchyna, and Sasiv. This popular tourist route features palaces, castles, churches, museums and other cultural heritage sites from different periods.

Using topographic map vectorisation, object classification and SRTM data in ArcGIS, a 2D vector digital map (Fig. 11) and a 3D digital model of the Golden Horseshoe of Lviv Region (Fig. 12) with the tourist route and attractions marked were created. A shapefile of point objects was created, and all information about the objects marked on the map, i.e. descriptive data and photographs of the objects, was entered into the database.

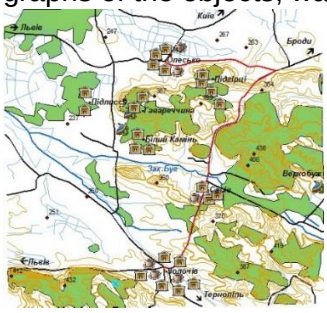


Figure. 11 The example of 2D digital terrain model (vector map)

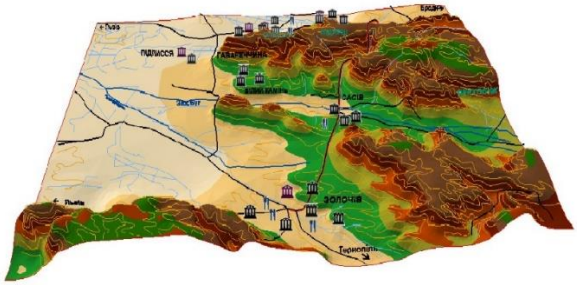


Figure. 12 The example of the 3D digital terrain model (DTM)

Information about objects and photos is displayed in the information windows, as shown in Figure 13.

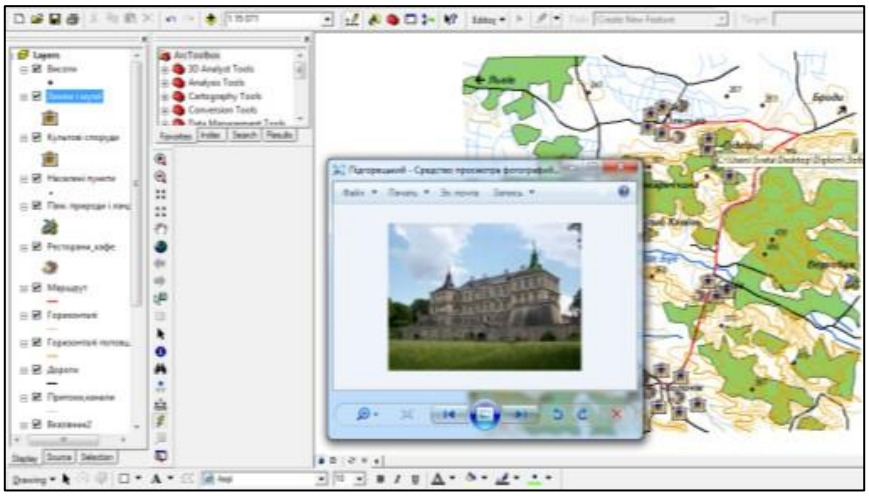


Figure. 13 Selecting an object on the map and visualising it in the information window

Thus, information and reference GIS is one of the ways to preserve, visualise and inventory cultural heritage sites.

Another way to digitally document and visualise historical and natural monuments is through augmented reality technologies and virtual tours [24,25]. They can be used both for ecotourism and in the monument protection industry.

A statistical virtual tour is a sequence of several combined panoramic or ordinary photographs connected by interactive links - hotspots - with the help of which, in the process of viewing, you can visually "move" using special transitions and interact with objects that are part of the image.

Virtual tours are primarily designed for users to get acquainted with sights and interesting places, allowing them to travel in space and time. At the same time, a virtual tour is a means

of displaying and documenting historical, cultural and landscape monuments, can accumulate and store various graphic and descriptive information, and therefore can be successfully used for modern documentation of cultural heritage sites. We created a virtual tour for the Golden Horseshoe of the Lviv Region route.

At first, we took cylindrical panoramic images of objects in all locations using Google Photo Sphere. The virtual tour was developed in Tourweaver. We designed a user-friendly interface and uploaded a map with the route and points of interest. There are two ways to access the objects of the route: through the symbols on the map (Fig. 14) or through the tabs with the corresponding names in the project environment (Fig. 15).

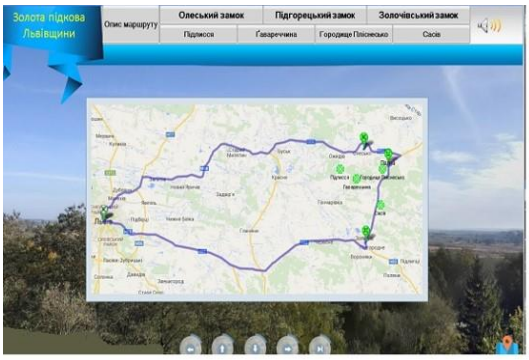


Figure. 14 The map of the virtual tour

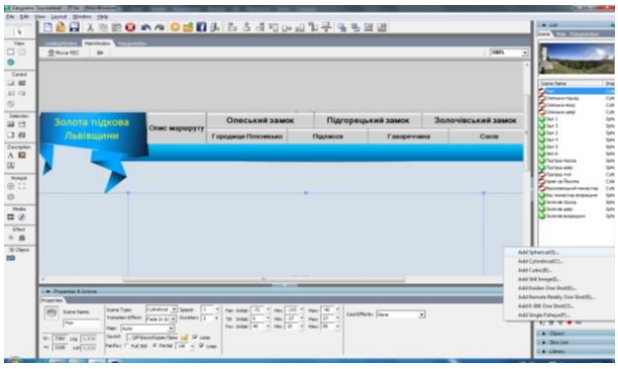


Figure. 15 The menu in the programme for selecting objects of the tour

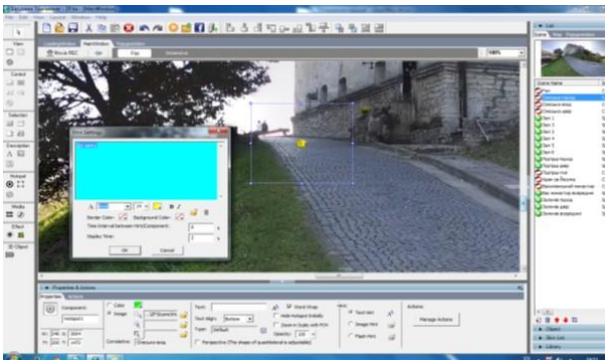


Figure. 16 Setting up the transition between scenes

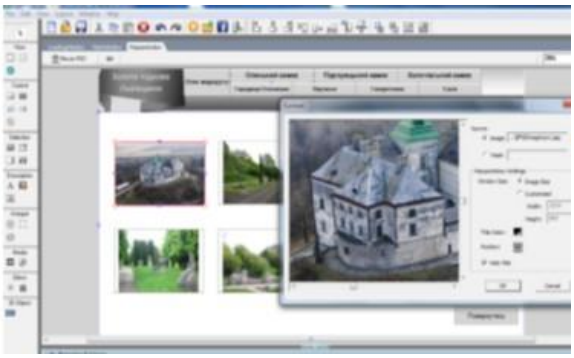


Figure. 17 Graphical and descriptive database

The main action of the Tourweaver software environment is to Link to the scene (transition to viewing between scenes of the virtual tour), Fig. 16. A graphical and descriptive database is formed for each object (Fig. 17).

The virtual tour "Golden Horseshoe of Lviv Region" we developed is an example of visualisation and documentation of cultural heritage sites in the context of the historical and natural environment.

The castles and palaces along this route now house museums that are administratively part of the Lviv Art Gallery. The created virtual tour was transferred to the digital archive of the Lviv Art Gallery.

3.4. Ground-based digital survey and modelling of monuments in specialised software

One of the most affordable ways to digitally document monuments for their inventory is to take ground images and process them in specialised object modelling software, such as Autodesk ReCap Photo 360 or the PolyCam 3D mobile application.

Let us consider an example of visualisation of the monument "To Lviv Polytechnic Teachers who died during the Second World War" in ReCap Photo [26]. The ground survey was carried out with a mobile phone around the monument at different heights using a selfie stick, with a photographic base of approximately 0.5 m and a distance of 2 m to the object. As a result, more than 50 photos were taken and uploaded to the app (Fig. 18). ReCap Photo allows you to use digital images to create three-dimensional models with Textured (Fig. 19) and Shaded, Wireframe, and X-ray models. Models are generated automatically in the cloud service. 3D virtual models of objects, their descriptions and video files are stored in tabular databases.

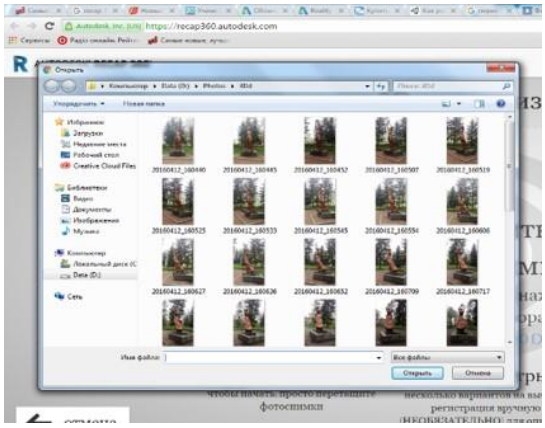


Figure.18 The examples of images used for 3D shape generation

Figure. 19 The generated textured model of the monument

This method of documenting and video archiving cultural heritage objects does not require significant resources and is recommended for implementation to record historical, cultural and monumental art monuments.

4. Summary

Modern non-destructive remote sensing methods and digital technologies for collecting and processing large data sets can significantly expand the possibilities of documenting and inventorying cultural heritage sites.

The aim of the article was to present examples of the use of non-destructive techniques in the inventory of objects and sites of cultural heritage in Lviv and its immediate surroundings.

An integrated approach is proposed to solve the problem of documenting cultural heritage sites. The advantages of precise remote sensing methods, object measurement and modelling, and spatial information systems (GIS) are used. In particular, GIS functional modules and tools allow mapping territories through digital elevation and terrain models, spatial modelling and positioning of monuments, and organising a large graphical and attribute-integrated database for storing and managing data on objects.

In this study, several examples were presented, and various modern technologies for collecting and processing information were used, including digital ground photography, close-range photogrammetry, ground laser scanning, unmanned aerial vehicles, and GIS. The experiments resulted in virtual models of monumental structures, an orthophoto with a frontal

view of an archaeological site, digital models of cultural landscapes, a geographic information system and a virtual tour of Lviv and its surroundings. A GIS database is a powerful tool for storing descriptive and graphical data about objects, and it can integrate and store data of various types. We propose using these digital documentation methods and video archiving in monument protection activities.

As we can see, the reality is that there are many threats to the existence of material cultural heritage sites in the world. Humanity may lose priceless masterpieces of architecture, art or natural monuments forever. Therefore, an early inventory of them and the creation of accurate digital models guarantee their preservation, rescue and reconstruction.

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