An Ontological Approach to the Formation of an Excursion Route by Heritage Objects in GIS

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Keywords: Heritage Objects, 3D Models, Ontological Model, GIS, Excursion Route.

Abstract: The paper presents an ontological approach to the consolidation of heritage objects 3D models and geoinformation systems for the virtual excursion routes formation. Given research purpose is to provide the opportunity for free mass access to the digitized heritage of the world civilization using augmented and virtual reality in three-dimensional space. Modern approaches and the most common software for 3D modelling of heritage objects are analysed. Software solutions for data 3D representation and analysis in GIS are listed. It is shown that the most suitable for practical implementation is GIS with integrated 3D panoramas of heritage objects. An ontological approach to the consolidation of multi-format data is described, it provides a solution to the problems of heterogeneity and interoperability of transdisciplinary distributed information resources that describe heritage objects. An ontological model of an excursion route is presented; its taxonomy is implemented in the form of a graph.

1 INTRODUCTION

In recent years, the process of digital society development has led to the need for remote communication. Various circumstances such as long business trips or remote work of employees, territorial distribution of jobs, active interaction with foreign partners, training and distance learning of staff and other unforeseen circumstances (such as quarantine during a coronavirus pandemic) forced to move organizations work processes to digital space[1]. The priorities were the organization of geographically distributed workplaces, systems, databases and knowledge into a single environment, high-quality visualization of information that simplifies its perception, analysis and assimilation, as well as ensuring functional space flexibility and adaptability for user interaction.

The formation of the information society and knowledge economy has enriched the modern vocabulary with the concept of "virtuallity", which came into use not only in the context of information and communication industry and business, but also culture and education. A clear illustration of this fact on a global scale is the understanding of the need to protect the accumulated in html-format global knowledge, as well as reaching an international consensus on the collection, preservation and dissemination of digital documentary heritage, as stated in the UNESCO Charter on Digital Heritage (United Nations Educational, Scientific and Cultural Organization, 2009). Over the past few years, access to global information resources has undergone qualitative changes: the world's leading heritage objects (museums, libraries, archives, etc.) have made the transition from a passive form of interaction with the civilization heritage (digital collections, electronic collections, databases, etc.) to active, providing opportunities for virtual travel through the centres of historical, cultural and scientific knowledge. The latest augmented and virtual reality technologies, interactive elements, three-dimensional interfaces have become an integral attribute of a modern digital heritage object.

Relatively new technology of creating virtual routes for tours and excursions is Geographic Information System (GIS). It was previously used exclusively in geography, land management, civil

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Honchar, A., Popova, M. and Novogrudska, R.
An Ontological Approach to the Formation of an Excursion Route by Heritage Objects in GIS.
DOI: 10.5220/0010406901700176
In *Proceedings of the 6th International Conference on Internet of Things, Big Data and Security (IoTBDS 2021)*, pages 170-176
ISBN: 978-989-758-504-3

engineering, transport infrastructure development, urban planning of any scale, architectural design and other areas that require storage and analysis of data from the objects schematic location in space. Although the basis of GIS is a digital map created in vector or raster graphics, as well as 3D panorama and panoramic photo, it is a graphical visualization of spatial data about the object. GIS includes data on the objects size and proportions, their relative position and 3D-panoramas (objects external characteristics in a panoramic photo).

The main and indisputable advantage of 3D-panorama and panoramic photo over geographic information systems is the reliability and realism of images not only in size and proportional data, but also in visual colour and texture. Although it is impossible a need to create a virtual route between heritage objects without GIS consolidation with 3D panorama. This tandem is the most promising and effective tool in creating a digital and at the same time natural system for the most accurate transmission of the most complete information about the real object in cyberspace.

The structure of the paper is following: Section 2 shows analyses of related works and backgrounds for the research. Section 3 gives data classification that is used to create GIS excursion route. Section 4 depicts ontological approach to such route formation. Section 5 presents conclusions and plans for future research.

2 STATE OF ART AND BACKGROUNDS

2.1 3D Modelling of a Heritage Object

Nowadays the most popular methods for creating a 3D model of a heritage object are digital panoramic photo and video capture, including using UAVs (Iglesias Martínez, 2019), and laser scanning (Klapa, 2017).

Ground-based laser scanning technology allows in a short time obtaining a three-dimensional image of the object in the form of discrete points with spatial coordinates (x, y, z) and with qualitative surface characteristics (light absorption, colour, etc.). Due to the accuracy of positioning and measurement density, it becomes possible to analyse the object as a whole that allows most fully reflecting it in the model. The high shooting speed of the laser scanner (up to several thousand and even tens of thousands of measurements per second) and the built-in servo-drive allow reducing time of field works and to minimize influence of the human factor. Also an important advantage of such technology usage is the capture of inaccessible or inaccessible objects due to the fact that laser scanners shoot at a considerable distance in a reflective mode.

For heritage object 3D-modeling specialized programs (Real Works Survey (RWS), 3Dipsos) and software products for three-dimensional design (Autodesk Inventor, Autodesk Civil 3D) are used. They are designed to process laser scanning data. This allow performing modelling in several ways, that is very important for heritage objects, where the density of exhibits is extremely high and many of them are difficult to access. The laser scanning model of a heritage object can be converted by software into a set of drawings, sections and sections, which are part of the standard design documentation during construction. Thus, this model can be used to support the research activities of architects, historians and more.

Despite all the advantages, laser scanning technology is expensive, and data processing techniques are still evolving.

The process of creating a 3D model of a heritage object with photo panoramas consists of photographing the object, processing and composing images, creating the final files. For high-quality panoramic photography, it is recommended to use a tripod and a special panoramic head, digital camera, lens (wide-angle or Fisheye type), a trigger for the camera (Dovgyi, 2016). Upon completion of the photography process and creation of an equilateral projection to form a continuous seamless panoramic image, stitching of a series of original photographs is performed:

- conversion of original photographs to a form suitable for stitching (reduction to cylindrical or spherical projection);
- own stitching (combination of identical elements in adjacent common areas of images);
- mixing images to equalize their brightness,
- contrast and colour tone.

Today there are many commercial (Adobe Photoshop, Pano2VR, Easypano Panoweaver, ArcSoft Panorama Maker, Panorama Plus Starter Edition / X4) and free or those with a free trial (Autopano Pro / Giga, Hugin, Microsoft Image Composite Editor) programs for creating 3D panoramas. The most common software is the software product PTGui (PTGui guidance, 2020), which has a wide range of tools for creating panoramas and has a clear interface.

The last stage of the heritage object 3D modelling is the combination of a ready-made 3D-panoramas series in so-called virtual tours or walks, where the transition from one panorama to another is carried out through hotspots placed directly on the images as navigation elements and/or floor plan. Pano2VR (Du, 2015) tool is most often used for this purpose. It allows not only forming a template using a room plan and setting the navigation logic within a virtual tour, but also to link multimedia content elements to active points using the developer interface (Flash API).

The 3D model of the heritage object is the main source of information to develop 3D GIS, which then forms a route for a virtual tour.

2.2 3D GIS for Creating Excursion Routes between Heritage Objects

Traditionally, GIS is designed to store and analyse information about spatial phenomena in order to gain knowledge about the world around us. According to (Campbell, 2020), the functionality of GIS includes the collection, structuring, manipulation, analysis and presentation of data. Three-dimensional geographic information systems allow viewing objects located in the area in 3D, as they look in real life. Indeed, 3D GIS aims to provide the same functions as 2D GIS, but, unfortunately, there are almost no 3D systems that can fully and autonomously provide the process of creating and using heritage objects. Several types of software are used simultaneously to extract and manage the necessary information, its analysis and presentation, including in three-dimensional form (for example, 2D GIS, DBMS and CAD). Due to the shortcomings of such systems in processing 3D objects, the data is often distributed between several systems. For example, one system is used for data storage and the other for 3D visualization. Such situation often arises due to problems of inconsistency, that leads to unnecessary time, effort and money spending to find a solution.

To date, there are several ready-made commercial solutions that can be classified as three-dimensional data representation and analysis systems. A significant share of the GIS market is occupied by such systems as: 3D Analyst with ArcGIS (ESRI Inc.), Imagine VirtualGIS (ERDAS Inc.), gvSIG (gvSIG Association). They offer some functions of three-dimensional data processing.

There are also some examples of integration of data management applications with GIS on the example of platforms Autodesk Revit Series (Niu, 2015; Wing, 2019; Baik, 2015), Google Earth (Niu, 2015; Wing, 2019), Autodesk Infraworks (Giudice, 2014), Autodesk 360 (Sergi, 2013), Autodesk Civil 3D (Butenko, 2020), LandXplorer CityGML Viewer (Blut, 2017), QGIS (Iadanza, 2015) and VISSIM (Wang, 2014). Such software solutions are usually focused on the visualization of geometry, rather than on geodata modelling (including topology and thematic attributes) or on the analysis of three-dimensional geospatial and temporal data. All analysed systems have little functionality of 3D GIS in terms of three-dimensional structuring, three-dimensional manipulation and three-dimensional analysis, but most of them can effectively process three-dimensional data in terms of three-dimensional visualization. A fully integrated 3D GIS solution has not yet been offered by GIS vendors.

Although our lives are in three dimensions, until recently, commercial GIS was largely limited to processing only two dimensions. Both relevant hardware and software were lacking, and the reason for this shortcoming was the insufficient and expensive acquisition of 3D geodata. The obvious reason for the lack of practical full-featured three-dimensional GIS implementation is that the transition to 3D means an even greater variety of object types and spatial relationships, as well as very large amounts of unstructured data. A full-featured 3D GIS must be a true 3D GIS (geographic information and analytical system).

3 DATA CLASSIFICATION FOR CREATING GIS EXCURSION ROUTE BETWEEN 3D-MODELS OF HERITAGE OBJECTS

The initial data for the integration of heritage object three-dimensional model, modelling of its environment on the ground, and development of the route for the tour are:

- vector map - a set of descriptions of passport data about the map sheet (scale, projection, coordinate system, rectangular and geodetic coordinates of the sheet corners, etc.), metric data of map objects (coordinates of objects on the ground) and semantic data of map objects (different properties of objects);
- height matrix that contains the absolute heights of the terrain where the heritage objects are located;

- triangulation relief model containing triangles of an irregular network describing the terrain surface;
- map classifier - a set of descriptions of vector map layers, types of objects and their symbols, types of semantic characteristics and their accepted values, presented in digital form;
- library of objects three-dimensional models - contain descriptions of the three-dimensional type of objects.
- digital terrain photographs and digital objects photographs.

While displaying interiors three-dimensional models there can be used individual objects and entire interiors, created in various programs for editing three-dimensional images and imported into the library of three-dimensional images of the classifier vector map GIS (Pierdicca, 2019; Fortino, 2016; Chianese, 2014.).

Three-dimensional visualization in 3D GIS requires appropriate three-dimensional spatial analysis tools. They allow easily moving between large models in real time. Studies of the demand for 3D GIS, in particular 3D City, demonstrate the advantage of users' choice in favour of photo-texturing, which causes the need to store additional data (values of model parameters) to overlay on the geometry. Therefore, the most suitable for practical implementation in terms of attracting time, labour and financial resources is an integrated GIS with 3D modelling of the heritage object from photo panoramas.

4 ONTOLOGICAL APPROACH TO THE FORMATION OF THE EXCURSION ROUTE IN GIS

GIS, in the sense of integrating semantic and geometric data, as well as spatial relationships, seems to be the most suitable system for analysing large amounts of data and thus for servicing many applications and routines. Therefore, developers working with spatial or semantic information have been trying to achieve GIS functionality for many years. CAD developers (such as Autodesk, Bentley) create tools for linking two-dimensional and three-dimensional geometry with semantic data and the organization of topologically structured layers. DBMS developers (Oracle, Informix) introduce spatial descriptors to represent geometric data and support them together with semantic data. The consensus on how to present, provide access and organize the dissemination of spatial information are the OpenGIS specifications (Geospatial Information and Standards, 2020), that allow directing the efforts of software developers and researchers from different fields of knowledge in one direction - the development of functional GIS. As a result, the role of the DBMS is changing, it should become a geo-DBMS - an integrated "container" of semantic and geometric properties of real objects, that will provide functionality for storage, retrieval and analysis of spatial data.

There is a considerable amount of researches on the three-dimensional data structuring, but they all are centered on several basic ideas. Each of the proposed data structures demonstrates the effectiveness and shortcomings in relation to specific programs and operations that need to be performed. However, to ensure the full functionality of 3D GIS the issues of three-dimensional buffering, the shortest three-dimensional route and three-dimensional interdependence must be solved. The integration of object-oriented approaches with 3D GIS shifts research emphasis from standard descriptors of objects and operations towards databases.

Thus, when creating a virtual tour route, a necessary step is to add its characteristics to the simulated heritage objects, and, consequently, to create a database. With the help of modern software solutions on the three-dimensional model, it is possible to create the required number of active zones, which are used to navigate hyperlinks to distributed information resources (databases, electronic systems, text, spreadsheet, multimedia content, etc.) or query the internal database where stored information about instances (exhibits) of the heritage object. However, this way of providing access to information resources is accompanied not only by organizational difficulties (time, labour and financial costs), because there is always a risk of information loss due to changes in the virtual address of the information resource, but also requires to solve number of problems such as heterogeneity and interoperability of transdisciplinary information resources. Database usage allows reading, entering, modifying and deleting data quickly and efficiently. But when creating a route for a virtual tour, it is in need to ensure the aggregation, integration and consistency of information resources included in 3D models of storage objects created in different formats according to different standards and technologies.

Computer ontologies are promising solution for various data sources integration that solve problems of data structural and semantic heterogeneity, their interoperability, elimination of inconsistencies and uncertainties, etc. Nowadays, ontologies are an essential element of many applications, used in agent systems, knowledge management systems, e-commerce, robotics, telecommunications, and medicine. The formation of a virtual tour as a system of knowledge about the heritage objects that is presented in the form of integrated distributed information content is most effectively implemented on the basis of ontology as a semantic model of the subject area. Ontology can also serve as an effective tool for finding and aggregating information from heterogeneous sources, presentation and interpretation of transdisciplinary information in the research process (Dovgyi, 2013; Stryzhak, 2014; Globa, 2018).

The ontological approach to the formation of tour route in GIS provides communication between: systems (GIS and 3D-panorama); users and systems (acting as a "single window" of access to semantically related contexts of information resources); and users with each other (defining common vocabulary of virtual tour users who need to interact with the information). The structure of ontology allows displaying the specific tasks of the integrated information environment and provides opportunities for their solution in the ontograph environment when necessary analytical tools are disabled in the environment of the geoinformation system (Popova, 2013).

The algorithm for forming a tour route includes the following steps:

1. Creation of heritage objects 3D models with photo panoramas.
2. Formation of heritage objects ontology and its integration into the created 3D-models (Figure 1).
3. Creation of 3D GIS for integration of heritage objects ontomodels.
4. Formation of an ontological excursion route (Figure 2).
5. Synchronization of the ontological excursion route with 3D GIS (Figure 3).

Information modelling of heritage objects is an information technology for displaying real objects with virtual elements of their description. The combination of 3D-panoramas and GIS provides the necessary know-how to build a reliable model, method and technology of knowledge management about the heritage of world civilization.

The infographic model of the ontological excursion route can be formally represented as:

$$O_{rout} = \{X, R, D_o, D_{GIS}\} \quad (1)$$

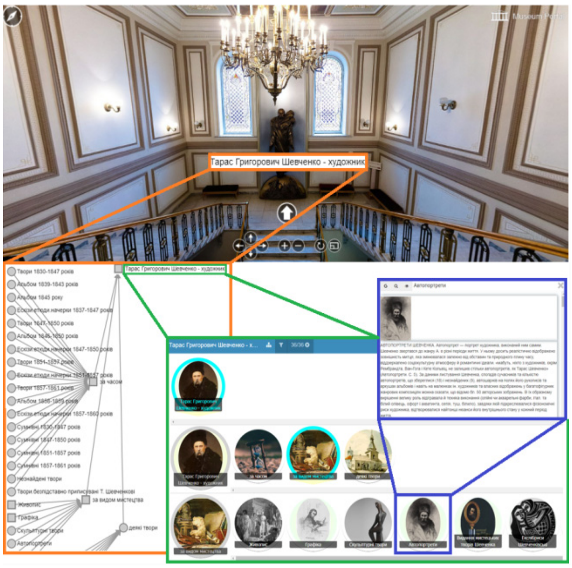

Figure 1: Integration of ontology and 3D panorama.

Figure 2: Formation of an ontological excursion route and its synchronization with 3D GIS.

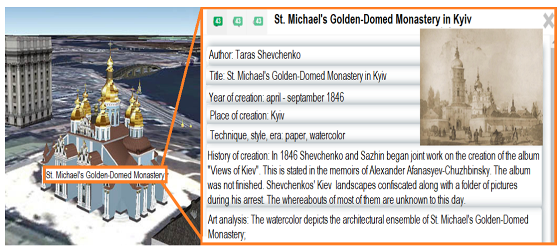

Figure 3: Consolidation of excursion route fragment (heritage object ontological 3D-model) with 3D GIS.

X – is the set of heritage objects included in the route $X = \{X_M, X_L, X_A, \ldots, X_{obj}\}$,

where X_M – set of museums: $(x_{M1}, \ldots, x_{Mn}) \in X_M | X_M \subset X$

X_L – set of libraries: $(x_{L1}, \ldots, x_{Ln}) \in X_L | X_L \subset X$

X_A – set of archives: $(x_{A1}, \ldots, x_{An}) \in X_A | X_A \subset X$.

X_{obj} – set of other defined objects $(x_{obj1}, \ldots, x_{objn}) \in X_{obj} | X_{obj} \subset X$.

R – set of relations between heritage objects that determine the direction and sequence of inclusion in the route.

$$R = \{R_M, R_L, R_A, \ldots, R_{obj}\}\} \quad (2)$$

D_o – set of ontological descriptions of the steps from which the route is formed.

D_{GIS} – set of actions descriptions that are performed in GIS to synchronize the display of the ontological tour route

The basis of the ontology of the excursion route is a taxonomy represented by a set of bipartite graphs *G:* $G = (N, E)$. Here the vertices are names of heritage objects – *N*, $(N_{obj1}, \ldots, N_{objn}) \in N_{obj} | N_{obj} \subset N$, grouped into classes (according to the type of heritage object - museum, library, archive, etc.); and arcs are represented by semantic relations between classes, based on them objects are grouped into classes by their properties:

$$(G_M, G_L, G_A \ldots, G_{obj}) \in G_{tour}\} \quad (3)$$

Since in real life the tour route is not homogeneous - one that includes heritage objects of only one type (for example, only museums dedicated to the life and work of Taras Shevchenko), a dynamic redistribution of objects is provided during the tour (for example, tour depicted in Figure 2 includes: a bust of Taras Shevchenko at the metro station University (1) - a Shevchenko monument at Tereshchenkovskaya Street (2) - National Museum of Taras Shevchenko (3) - a bust of Taras Shevchenko on the facade of the National Academic Opera and Ballet Theater of Ukraine (4) - Taras Shevchenko Literary Memorial House-Museum (5) - St. Michael's Golden-Domed Monastery in Kyiv, depicted in watercolour by Taras Shevchenko in 1846 (6)), that can lead to the formation of new classes of taxonomic objects (Gonchar, 2019):

$$G_M \bigcup G_L = \{G(N, E) | N_M \subseteq N, N_L \subseteq N, E_M \subseteq E, E_L \subseteq E\} \quad (4)$$

$$N_M \cap N_L = \{N | N \in N_M, N \in N_L\}\} \quad (5)$$

The process of tour route forming in taxonomy environment is reduced to solving the problem of salesman on the graph with further displaying in GIS environment.

5 CONCLUSIONS

Consolidation of geographic information systems with 3D-panorama create an innovative tool for the formation of excursion routes by virtual museums, that provide new opportunities in the study of world cultural, historical, scientific and digital documentary heritage.

The ontological approach to the formation of the tour route that was proposed in the research is universal. It takes into account the features of the knowledge field, the representation of which is the heritage object through transdisciplinary integration of distributed information resources that describe ontological model of the selected object. Proposed approach automated the formation of the tour route and its components (virtual tours of individual heritage objects) by creating ontological descriptions of each step.

Usage of described approach for tour route formation allowed automating its display in GIS, which is a distinctive feature of real-time systems, because depending on the available data the most optimal route can be selected for the shortest period. Ontology usage as information model of heritage object made it possible to automate the formation of the educational and research environment, which best corresponds to researcher's level of training and his scientific profile.

Further researches would be devoted to a more detailed consideration of the excursion routes automated generation from sets of ontological three-dimensional models, as well as to the software implementation of the proposed approach.

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