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The use of augmented reality for renovation of cultural heritage sites

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ABSTRACT

Augmented reality is an innovative technology that merges the virtual and real worlds to create a unique interactive experience for users. Although the technology only became widely known in the mid-2000s, its potential and applications continue to evolve rapidly, especially with the advent of smartphones and other mobile devices that allow a wide range of users to interact with augmented reality in their everyday lives. In the field of cultural heritage and tourism, augmented reality opens up new opportunities for the restoration and presentation of historical buildings and places that no longer exist or have been altered by time, giving visitors the opportunity to see and experience the historical environment in its original form. However, to effectively use augmented reality in this area, it is necessary to ensure an exact correspondence between virtual objects and the real environment, as well as to implement navigation functions that will help users easily navigate the virtually restored space. Developing and implementing augmented reality solutions requires not only technological expertise but also a deep understanding of the historical, cultural and social context of the objects being recreated. Based on our research, we have developed a concept of an augmented reality application for the reconstruction and promotion of cultural heritage. This includes methods for accurately recreating historical locations and objects in a virtual environment, as well as developing intuitive navigation tools for users. The main achievement of the work is the creation of a foundation for the further development of augmented reality technologies in this area, with a focus on improving the interaction between virtual and real components, which will help increase audience engagement and raise awareness of historical and cultural heritage. This opens up broad prospects for the use of augmented reality for cultural heritage, and the proposed approaches can serve as a basis for future innovative projects in this area.

Keywords: Augmented reality; virtual reality; 3D modelling; renovation; cultural monuments.

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INTRODUCTION

Augmented reality (AR) [1] is a rapidly developing technology that displays virtual objects in the real world. It is already used in many industries, such as the gaming industry, navigation, tourism, etc. By overlaying virtual objects on physical environments, the blending of the virtual and real worlds provides people with a new experience of everyday life. For cultural heritage, the social, historical, cultural, and educational value of AR is being explored, for example, for the reconstruction of cultural heritage sites [2]. AR reconstruction is a type of application that relates to tourism, cultural heritage, and archaeology. Its peculiarity is the reconstruction of objects using AR technology as if they existed in the same place [24]. Augmented reality is especially useful for applications related to cultural heritage, as most parts of ruins are usually missing and invisible, and it is difficult to imagine how they looked in the past just by visiting the place. With the help of AR, ancient buildings can be recreated and presented to appreciate their ancient appearance.

In the context of this paper, the following terms are used.

The term "renovation" is used to describe a comprehensive process of restoring, updating, and adapting historical architectural structures, facades, interiors, and other elements of cultural heritage that have become morally or materially outdated. This process involves not only the physical restoration of architectural objects but also the application of modern technologies to provide new life to historical buildings while preserving their authenticity and cultural value.

Additionally, we use the term "virtual restoration". "Virtual restoration" refers to the process of creating virtual models of historical objects in their original appearance using augmented reality technologies. This process allows for the detailed reproduction of the external appearance and atmosphere of historical sites without physical intervention.

Note that the term “renovation” describes a broader process of physical restoration, modernization, and adaptation of historical objects to contemporary needs while preserving their cultural and historical value.

One of the earliest applications of AR was ARCHEOGUIDE, introduced in 2000. At that time, creating AR effects required the use of multiple sensors and devices. Most research at that time focused on overcoming technical challenges, with little attention paid to user interface design principles during development. The problem may arise due to difficulties associated with differences and rapid changes in hardware capabilities and device availability. At the current stage, some research has focused on this issue and proposed principles and recommendations for mobile AR. With the advancement of technology and mobile devices, the AR experience becomes more accessible and popular, especially with the release of the mobile game AR Pokémon GO in 2016. Although some design principles from the perspective of user experience, interface, and heuristic evaluation have already been developed, their implementation poses challenges for AR reconstruction due to its specific characteristics.

It should be noted that cultural heritage sites around the world are currently under constant threat from environmental crises, wars and the effects of time. Therefore, it is very important to create digital 3D models of these objects [3], which can help identify their damage and facilitate the restoration process. At the same time, an urgent task is to create a concept for an AR application that will use these models to restore cultural heritage.

In view of the above, this study aims to develop the concept of a prototype application of an innovative information system focused on the preservation and restoration of important cultural heritage sites.

For this purpose, we propose the new methods, in particular: (i) a method for determining the correct location of an object, which helps users to visualise better the results of renovation; (ii) a method for improving 3D models of cultural heritage objects that allows for a visual assessment of the potential of renovation works; () a method for displaying specific cultural heritage objects in augmented reality, which provides additional information about the history and significance of each object.

These methods are aimed at achieving several key goals of renovation: preserving the historical value of objects while adapting them to modern requirements, attracting a wide audience to study cultural heritage through the latest technologies, and raising awareness of the need to protect historical monuments.

1. ANALYSIS OF LITERARY DATA

The current situation regarding the preservation of cultural heritage requires the immediate action and attention. Cultural heritage sites around the world are under threat from a number of physical factors, such as environmental disasters, damage from conflict and war, and natural decay over time. Preserving and protecting these sites is a crucial task, as it means not only protecting their tourist value, but also preserving our cultural identity and history.

There are many cultural heritage sites in Ukraine that require restoration and rehabilitation. However, there are certain problems that complicate this process. The key one is the lack of access to accurate information about the condition of cultural heritage sites, their shape, colour, texture and materials, which complicates their restoration and recovery.

The second problem is the need to implement an efficient workflow to optimise the resto-ration process and ensure its quality. Without this optimised workflow, restoration work can be protracted and inefficient, which can lead to de-lays, loss of restoration quality and unnecessary costs.

One of the ways to solve these problems is to digitise and visualise the cultural heritage in virtual space, which has already been explored in various projects. It should be noted that due to significant technological advances in recent years, more and more projects are being implemented in augmented reality, which has its advantages and disadvantages compared to virtual reality. The ability to see the real environment while using the application can be useful, especially when over-laying certain objects on real locations.

Examples include the following projects: AR tours implemented in the Louvre in Paris [6], 3D modelling of the Ramintoji Church in Vilnius, Lithuania [7], a HoloLens framework for MR visualisation in the Temple of Neptune in Pestum, Milan Cathedral and part of the porticoes in Bologna [8].

Similarly, during the AURA project [9], the possibilities of digitisation and auralisation were explored and tested at cultural heritage sites in Germany, Italy, and Ukraine. The Concert Hall in Berlin, the Teatro La Scala in Florence, and the Opera and Ballet Theatre in Lviv were digitised using laser scanning and photogrammetric procedures, and were audio and eventually visualised in virtual reality. This created a multisensory experience that reflects both the appearance and acoustics of the halls. These applications formed the basis of case studies that focused on the benefits for tourism and business model development [10].

In addition, it is worthwhile to discuss existing research on mobile augmented reality and mobile applications for reconstruction. Regarding AR applications, only the interface and design of AR applications are studied, and the AR effects of existing applications are not included in this research. Most of them use 3D models to show the reconstruction. Some applications use 2D historical photographs to overlay specific scenes. Some 3D models are recreated as complete buildings. Some models only recreate the missing parts and preserve the existing structure. For example, Cannella has developed this type of AR reconstruction for both outdoor and indoor environments [11]. In the internal museum, a reconstruction of an old temple was recreated, which was reflected and matched the ruins of the temple to show their interconnection. The effect allows you to clearly see which parts are recreated.

The appearance of 3D models can be applied to texture, light and shadow effects to make them more realistic. A study by Bobok et al. completed a full model of a Roman house, including interior spaces. There was also an animation showing Ovid, the ancient Roman poet, writing at his desk. When users enter the building, they can see the animation and even hear a voice reciting Ovid's poetry [12]. She used different types of multimedia together in the AR experience. As for special AR effects, the "ghost" effect is often used for reconstruction objects. Some applications provide a bar to adjust the transparency of virtual objects to users. This feature makes it more obvious to compare the difference before and after reconstruction.

Some apps use animations as a reminder to tell users where the targets are. Many apps pro-vide maps to show the location and distribution of points of interest. They can take different forms, such as web maps [13] or computer graphics-based maps [14]. Some of them display the current location of the user. Different layers of maps, such as historical maps and aerial images that show the current land surface, allow users to compare landscape changes in different eras. Signage for a suggested visit route can also be added to guide visitors. To show objects in different time periods, a timeline bar can be used for user selection [15, 16]. For simplicity, some applications show users the guides immediately after launching the application, some provide guides in the form of an icon that users can use if they have questions.

The results of the literature analysis are presented in Table 1.

Based on the analysis of literature sources, a number of shortcomings for existing solutions have been identified.

Among them:

1) poor quality of 3D models, their inconsistency with historical truth and lack of compliance with archaeological research;

2) insufficient balance between virtual content and additional text, audio, and video materials, which can lead to the predominance of one type of content over another and loss of information integrity;

3) the difficulty of selecting the most effective method of tracking objects, which may lead to insufficient accuracy and stability of the system;

4) a significant duration of the procedure for tracking and overlaying 3D models on images or existing monuments, which may cause user dissatisfaction due to the length of the process;

5) lack of a user-friendly interface.

2. THE PURPOSE AND OBJECTIVES OF THE RESEARCH

The aim of this study is to develop a prototype application based on augmented reality for the restoration and renewal of cultural heritage. Our application is aimed at supporting the process of digitalisation of museum collections, which is currently underdeveloped. By integrating digital copies of objects into the app, we aim to make cultural heritage more accessible to the general public, as well as provide new tools for research and education.

Table 1. **Existing applications for augmented reality reconstruction**

Source	Type	Opportunities
Cannella, 2019 [11]	AR research	The app displays the missing part of the building and provides a slider for adjusting transparency
Pettitt and Fuhrmann, 2017 [17]	AR research	3D reconstruction of Robinson's house in the Manassas National Battlefield Park
Boboc et al., 2019[12]	AR research	3D reconstruction of a Roman house with animation and voice
Cisternino et al., 2018[15]	AR research	Presents buildings from different historical periods and dynamically provides detailed information based on the distance between the mobile phone and the target
Lee et al., 2012 [13]	AR research	Displays virtual 3D buildings damaged by an earthquake. Features a map with pop-up windows showing points of interest
Kasapakis and Gavalas, 2016 [18]	AR research	Utilizes AR location with GPS. POI markers are placed in specific locations. Users can tap on markers to view explanations and images.
Rainio, Honkamaa and Spilling, 2015 [19]	AR research	Uses AR location to overlay historical photographs onto reality
Krogstie and Anne-Cecilie Haugstvedt, 2012 [16]	AR research	Displays historical photographs and provides a timeline slider for users to select scenes from different periods
Cavallo, Rhodes and Forbes, 2017 [14]	AR research	Uses markerless tracking to display historical photographs when the camera aligns with certain natural objects
Carnuntum APP	Existing application	Provides both AR and VR experiences for viewing reconstructions of archaeological sites
Aoyakamijichi AR	Existing application	Offers animation for target searching. Includes a guide feature for collecting virtual artifacts
Caistor AR	Existing application	Provides both AR and VR experiences for the Roman city of Caistor. Upon app launch, the user is presented with a guide. Features a map with a suggested visiting route and recommendations for activities at each location

Source: **compiled by the authors**

Main objectives of the study are:

1. Research of AR augmented reality technologies for the maintenance and reconstruction of cultural objects and development of methods for their renovation:

2. Development of the concept of a prototype application of an information system using augmented reality.

Virtual objects can be displayed in the real world through augmented reality devices, so the following main stages can be distinguished:

– Development of application scenarios.

– Development of the application concept.

– Development of training concepts and modules.

3. RESEARCH METHODS

Based on the above tasks, the following methods were used to develop the concept of a prototype of an application information system using augmented reality.

1. A method of determining the correct location of an object that uses orientation and object recognition sensors to determine where in the real world a virtual object should be placed.

2. A method of improving 3D models of cultural heritage objects, which involves accurate and detailed reproduction of the shape, colour, texture and materials of a cultural object.

3. A method of displaying specific cultural heritage objects in augmented reality, which will allow

creating a 3D model of a virtual replica of the object with the reproduction of original colours, textures and other details.

Let's take a closer look at each method.

In particular, in the **first method**, the key technology for displaying augmented objects in a certain location is tracking. It must be implemented with high accuracy, fast response, and low latency to achieve a good experience of using AR. Among the tracking methods, the most common are markerless, sensor, and hybrid tracking. Each tracking method is suitable for different environments. For example, marker-based tracking is not suitable for outdoor environments, as many studies have shown. Tracking methods are provided by software development kits (SDKs). Each SDK has its own features and supports different tracking methods. Most of them work on both iOS and Android devices. As for the SDK licence, some are free, while others are free with limited functionality. When choosing an SDK, you should consider your project environment, requirements, budget, etc. Table 2 shows a comparison of some common AR SDKs.

As for the **second method**, the reproduction of three-dimensional models is an integral part of the display of augmented reality. The main emphasis is on building objects with the correct scale and geometry based on historical accuracy. With the use of high-tech tools, archaeological sites or ruins can be recreated in a geometrically accurate and photo-realistic manner using photogrammetry or laser scanning. However, as seen today, the reconstruction of missing objects that cannot be seen in modern times is based on historical documents and data. There are many methods for building three-dimensional models. Regardless of the method, the ultimate goal is to achieve clear communication between models and users. In addition, the size of models can affect the performance of augmented

Table 2. **Comparison of some common AR SDKs**

SDK	**Tracking Methods**			**Platform**	**License**
	Camera	**Sensor**	**SLAM**		
Apple ARKit	2D, 3D Object Tracking	GPS, IMU	No	iOS	Free
Google ARCore	2D Tracking	GPS, IMU	Yes	iOS, Android	Free
ARToolKit+	2D Tracking	-	No	iOS, Android	General Public License
Wikitude	2D, 3D Object Tracking	GPS, IMU	Yes	iOS, Android	Free & Commercial
Vuforia	2D, 3D Object Tracking	GPS, IMU	Yes	iOS, Android	Free & Commercial
Kudan	2D, 3D Object Tracking	GPS, IMU	Yes	iOS, Android	Entrepreneurial
MaxSt	2D, 3D Object Tracking	-	Yes	iOS, Android	Free & Commercial
EasyAR Basic	Basic 2D Tracking	-	No	iOS, Android	Free
EasyAR Pro	2D, 3D Object Tracking				Commercial

Source: **compiled by the authors**

reality. A model with too much geometric complexity, shading, and rendering can hinder the augmented reality experience. The details of 3D models must be balanced be-tween user experience and hardware performance.

The presentation of augmented objects in the **third method** can be static or dynamic (interactive). A static presentation allows users to under-stand the information that is already displayed, while an interactive presentation helps users explore unknown parts. It can even increase their motivation to explore the application. Similar requirements for interacting with augmented reality can be compared to those for interactive mapping.

For a better understanding of the augmented reality user, Keil et al. developed the augmented reality visualisation cube, which is based on the MacEachern cartography cube. The cartography cube describes the level of human interaction with maps compared to visualisation communication. The task of discovering the unknown re-quires a higher level of user interaction and leads to more private use and individualised user experience. Therefore, users can form perceptions through interaction and create a pre-investigation visualisation of communication.

For the cube of augmented reality visualisation, the relationship between user interaction, informa tiveness and adaptability to knowledge transfer efforts is explained. A higher level of knowledge transfer effort, which means visual thinking, requires a higher level of interaction and informativeness.

It should be noted that for displaying augmented reality with low interaction, a static presentation is more suitable, which requires a higher level of user adaptability to understand the provided information. Meanwhile, for displaying augmented reality with high interaction, it is difficult to design information that should be high-lighted during the interaction process.

Regarding the interaction itself, transparency and object highlighting are common ways of interacting with archaeological objects. Additional text or image labels may be displayed in a fixed location to reduce interface complexity and avoid obscuring other objects. Users hold the mobile device to focus on the object with one hand and perform touches on the screen with the other hand. However, user fatigue during prolonged work and complex interaction gestures that re-quire more physical effort are possible. Therefore, interaction should be implemented using simple and intuitive gestures.

4. RESEARCH RESULTS

The analysis of the proposed methods allowed us to formulate three basic functions of the information system: data collection, virtual restoration, and interactivity. Based on the content of these functions, the general structure of the information system for the renovation of cultural heritage sites was synthesised [21, 22].

Information about cultural heritage objects for the application will be collected from a variety of reliable sources, including archives, historical registers, scientific publications, and documentation of museum collections. We are also working with historians, archaeologists, and restoration experts to ensure the accuracy and reliability of the objects in the augmented reality.

Based on this framework, we propose to focus on the study of use cases, the basis of the application concept that will be discussed further. These scenarios provide an opportunity for an in-depth study of the functionality of the application under development and its effectiveness in real-world use. Based on this, it is advisable to consider three examples of use cases:

***Scenario 1:* “**Virtual Restoration of Cultural Heritage”.

1) The restorer launches the application on their computer and enters their credentials to log into the system.

2) The system identifies the restorer and grants them full access to all functions.

3) The restorer selects an object for virtual restoration from the system's database.

4) The system loads the 3D model of the object and all available information about its condition, history, and other important details.

5) The restorer uses the system's tools to simulate the restoration process, including repairing damages, restoring lost details, and more.

6) After completing a certain stage of restoration of an object, the restorer saves the 3D model for further use and analysis, providing the opportunity to continue work on the next stage.

The app will be an important tool for restorers, as it will allow them to visualise the potential results of restoration work before it begins. This will facilitate better planning of the restoration process, including the choice of materials and techniques, and will also allow assessing the impact of the restoration on the overall appearance of the object. The difference from conventional 3D models lies in the interactivity and the ability to view models in real time and space, which greatly facilitates the understanding of the object and its historical context.

Scenario 2: "Augmented Reality for Virtual Tour of Cultural Heritage".

1) The user opens the application on their mobile device.

2) The application requests permission to access GPS and the camera. The user grants necessary permissions.

3) The system determines the user's location and offers a list of nearby cultural heritage objects available for virtual tours.

4) The user selects one of the objects.

5) The system loads the 3D model of the selected object and historical information.

6) After loading, the system displays this model in augmented reality through the mobile device's camera.

7) The user can rotate, zoom in, and zoom out the model, as well as read historical information about the object.

Scenario 3: "Museum Tour Using Augmented Reality".

1) The visitor opens the application on their smartphone while visiting the museum.

2) While in the museum, the visitor activates a themed tour that interests them.

3) The application provides the visitor with directions and virtual markers to navigate the area and find exhibits related to the chosen theme.

4) Upon approaching an exhibit, the application automatically provides additional information about it through augmented reality and reconstructs it.

5) The visitor can listen to audio guides, watch videos, or view photos that help enhance their understanding and experience of the exhibit.

The educational modules expected to be developed are aimed at integrating the developed prototype application into the educational process and expanding students' understanding of cultural heritage and its restoration processes [23]. Let us consider some possible aspects of application.

Firstly, this involves the development of educational materials such as video lessons, interactive presentations, infographics, and articles explaining the history, significance, and techniques of cultural heritage restoration.

Secondly, it entails creating virtual tours that allow students to explore restored objects in the context of their origin and history.

Thirdly, it is the development of practical tasks that will allow students to use the developed system for virtual restoration of objects in need of restoration.

Moreover, student projects aimed at exploring various aspects of cultural heritage and methods of its preservation should be encouraged.

Thus, the educational modules are aimed at creating a stimulating and in-depth learning experience that will help students uncover the potential opportunities and importance of preserving and restoring cultural heritage.

5. EXPERIMENT AND RESULTS

The overall concept of the proposed application can be represented by an architecture consisting of two main parts: the mobile client and the server (Fig. 1). The server provides a MySQL database containing records of monuments (name, description, latitude, longitude, etc.) and user-specific information.

The database is accessible to users through a RESTful web service. Basic registration is required to use the system. User functions include saving visit data, marked locations, and overall progress in a specific area, while monument information is sent in a format suitable for mobile devices.

The architecture of the mobile application is designed with scalability and ease of adaptation to changes in the core server model in mind.

It is based on three main layers (see Fig. 1).

The Views layer is where interaction with users occurs. Together with the background location service, they act as the main entry points into the system. Events that occur are forwarded to the Handling layer, which consists of two modules adhering to the Singleton pattern. The Data Handler is responsible for interacting with local content and communicating with views, while the REST client is responsible for communication with the web service.

The Model layer consists of basic auxiliary modules for parsing received JSON (JavaScript Object Notation) files and interacting with the local database. Actions transition from the Views layer to the lower components. In response to a user event or location update, a call is made to the processing layer, which accesses the model to retrieve the requested data.

The Handling layer is the most critical of the three because it handles interactions, information exchange, and synchronization. The REST client provides an interface for retrieving and sending information to the remote database as requested by other layers. It is responsible for sending data about user visits, saved locations, progress updates, and personal information.

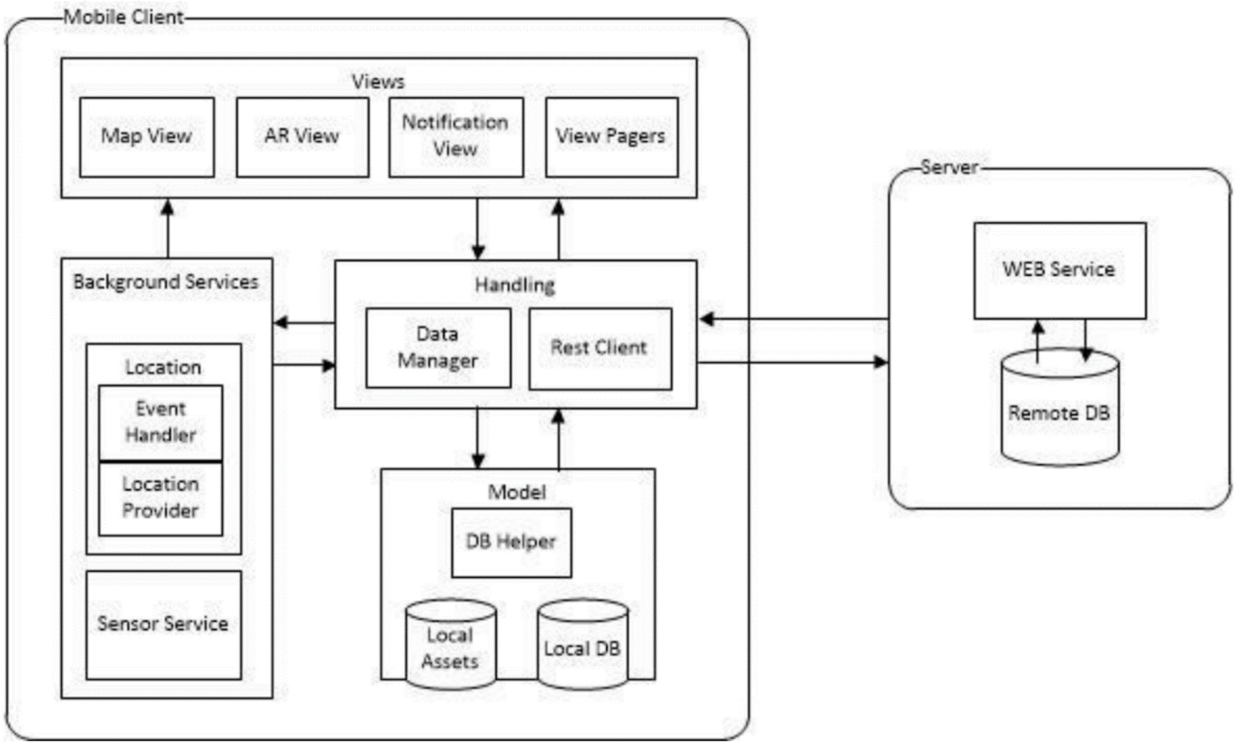

Fig 1. **Application Architectura**
Source: **compiled by the authors**

The Handling layer provides functions for retrieving data from the server regarding Points of Interest (POIs) and images. Additionally, it allows for synchronization and queuing of requests. While the REST client is responsible for interacting with the server, the data handler manages communication with local content.

The received information is analysed and stored in the local database (see Fig. 1). The handler responds to events from views and the background service and handles the business logic for other components. It structures and provides accessible information based on the program's state.

Views are the primary components of the user interface that facilitate interaction with users.

“MapView” is a fragment containing a two-dimensional map developed using the Google Maps API. It displays the user's location as obtained by the background service, as well as Points of Interest (POIs) represented as markers on the map.

The “**AR View”** is based on the Wikitude JavaScript API and is where augmented reality experiences occur. It's a web view with a transparent background overlaid on the camera surface. It displays 3D models of historical monuments, receiving location updates from the background service and orientation updates from the underlying sensor implementation. Additionally, it contains a `NavigationView` where POIs are displayed as labels in the real world. Interaction occurs using JavaScript and is independent of its own code.

“ViewPagers” are user interface elements specific to the framework that display lists of POIs, details for each POI, user leaderboards, and their profiles.

The “Notification View” component is used when the application is in the background and aims to manage the location service. It is a persistent notification in the system tray where the user can change location strategy settings and start, pause, or stop the service as desired.

The purpose of the background service is to allow users to navigate freely the city while receiving notifications about nearby POIs (Points of Interest). It is responsible for providing location updates obtained via GPS to both the Map View and AR View components. The location provider is a component that manages the retrieval of location data. It offers the option to switch between the Google Play Services API and the Android Location API, which are two different location strategies. To ensure control over battery life and data usage, users can adjust its frequency in the settings.

Views requesting location updates are registered as listeners to the location service and receive location updates containing latitude, longitude, altitude, accuracy information, and more. The location event controller is responsible for providing location events to registered views. The user's location is constantly compared to available POIs. If the corresponding distance is within an acceptable range, the user can interact with the POI. Sent events include entering and exiting an active POI zone. If the application is in the background, notifications are issued, leading to the AR View and Map View.

The **Model layer** consists of standard storage and processing facilities to allow parsing JSON files received from the server and interfaces for interacting with the local database. It stores historical information about the current location, user-specific information, and additional variables necessary to ensure optimal application flow. Local resources, including 3D models and HTML and JavaScript files required for the Wikitude API, are stored at this level and provided to the handler layer upon request. The SQLite helper is a component responsible for updating the local storage and providing an interface for handling interactable data.

The AR functionality is implemented using the Wikitude JavaScript API, which is based on web technologies (HTML, JavaScript, CSS). To integrate with the Android SDK, a special view component called ARchitectView is used, which is added to the activity layout. HTML pages are typically loaded from resources using an API to create AR objects. During the onCreate() call, ARchitectView is initialized, and an interface communicating with the pages is created..

Data is transmitted in JSON format, which is parsed to obtain arguments for the AR experience. The AR activity is launched from the map activity via the internet, which contains a key-value pair for selecting the AR experience. Three AR interactions have been developed: ARNavigation, 3DModelAtGeoLocation, and InstantTracking, each of which is a separate HTML page loaded upon creation of the AR activity. After initialization, the activity binds to the LocationService to receive location updates, which are sent to the ArchitectView for displaying AR objects on the screen. Each individual AR activity is responsible for initializing each AR page depending on the intent passed from the MapsActivity.

Creating each AR experience follows the standard web development process. The user interface (UI) contains a 3D scene with AR objects and standard 2D elements developed using JQuery for better content control. The AR navigation page displays camera screen scenes in their geo-locations. After the page is loaded, a JSON array with scene information is received, parsed, and for each scene, a marker object is created with its own animation logic for transitioning between selected and unselected states using AR.PropertyAnimations.

The purpose of the application server is to provide an online repository for historical and user information. It utilizes a RESTful web service to provide information to mobile clients.

On the server side, there is a database storing historical information and 3D models in “.wt3” format used by Wikitude, as well as user information for authentication and access control. Mobile devices request information from the server and store it in their local databases.

Data can be queried to provide personalized information to users and useful city statistics. The web API exposes its resources through unique user-defined URLs stored in the mobile client.

Each key object in the database schema corresponds to a relative path from the server's base URL. For each object identified with a URL, the client uses different types of HTTP request methods (GET, PUT, POST, and DELETE).

CONCLUSIONS AND PROSPECTS OF FURTHER RESEARCH

We explored the concept of creating a prototype application of information system using augmented reality for the preservation and restoration of cultural heritage. The analysis of literature sources has shown not only the relevance of this topic, but also the urgent need for innovative approaches to the preservation of historical monuments.

Based on the proposed methods and scenarios of their application, the concept of an AR-based application is developed, which demonstrates the potential of this technology in implementing an interactive and accessible method of cultural heritage research.

Such an approach not only contributes to the preservation of cultural heritage but also opens up new opportunities for education and tourism. For example, the implementation of educational modules based on AR can become a powerful tool for raising awareness about the importance of preserving cultural heritage among younger generations.

In general, the developed application concept can be an important step towards preserving and restoring priceless artefacts for future generations using the latest methods of research, education and interaction with cultural heritage.

The development prospects indicate the possibility of expanding the geographical and cultural diversity in the database of cultural objects, as well as improving the technological infrastructure of the project. This allows users to contribute to the development of the system and can contribute to the creation of an active community around cultural heritage. In addition, there is potential to develop professional courses for restorers using AR to improve their skills.

In the future, the use of polygon geometry will be explored to define and delineate areas of interest. Circles centred on latitude and longitude points simplify calculations based on location, and information is provided to the mobile device upon location request. Polygon geometry will be a significant factor in expanding the current model.

REFERENCES

1. Volynets, V. O. "Virtual, augmented and mixed reality: the essence of concepts and specificity of the relevant computer systems". *Issues of Cultural Studies*. 2021; 37: 231–243. DOI: https://doi.org/10.31866/2410-1311.37.2021.237322.

2. Arsirii, O. A., Troianovska, Y. L., Prykhodko, I. O. & Kotova, D. Y. "Architectural objects recognition technique in augmented reality technologies based on creating a specialized markers base". *Herald of Advanced Information Technology*. 2019; 2 (2): 108–121. DOI: https://doi.org/10.15276/hait.02.2019.3.

3. Schauer, S., Sieck, J., Lipianina-Honcharenko, K., Sachenko, A. & Kit, I. "Use of digital auralised 3D models of cultural heritage sites for long-term preservation". *IEEE 12th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS)*, Dortmund: Germany. 2023. p. 708–712. DOI: https://doi.org/10.1109/IDAACS58523.2023.10348637.

4. Tom Dieck, M. C. & Jung, T. H. 'Value of augmented reality at cultural heritage sites: A stakeholder approach'. *Journal of Destination Marketing and Management. Elsevier Ltd.* 2017; 6 (2): 110–117. https://www.sciencedirect.com/science/article/pii/S2212571X16300774.
DOI: https://doi.org/10.1016/j.jdmm.2017.03.002.

5. Dünser, A., Grasset, R., Seichter, H. & Billinghurst, M. "Applying HCI principles to AR systems design". *2nd International Workshop on Mixed Reality User Interfaces: Specification, Authoring, Adaptation (MRUI '07)*. 2007. Available from: https://ir.canterbury.ac.nz/bitstream/handle/10092/2340/12604890_2007-MRUI-Applying_HCI_principles.pdf;sequence=1. – [Accessed: Feb. 2023].

6. Plecher, D. A., Wandinger, M. & Klinker, G. "Mixed reality for cultural heritage". In: *IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 2019. p. 1618–1622. DOI: https://doi.org/10.1109/VR.2019.8797846.

7. Bertocci, S., Arrighetti, A., Lumini, A. & Cioli, F. "Multidisciplinary study for the documentation of the Ramintoja Church in Vilnius". *Development of 3D models for virtualization and historical reconstruction. DISEGNARECON*. 2021. 14 (27): 1–16. DOI: https://doi.org/10.20365/disegnarecon.27.2021.13.

8. Teruggi, S., Grilli, E., Fassi, F. & Remondino, F. "3D surveying, semantic enrichment and virtual acces of large cultural heritage". In: *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 2021; 8 (M-1-2021): 155–162. DOI: https://doi.org/10.5194/isprs-annals-VIII-M-1-2021-155-2021.

9. Schauer, S., Bertocci, S., Cioli, F., Sieck, J., Shakhovska, N. & Vovk, O. "Auralization of concert halls for touristic purposes", i-com, 2022; 21 (1): 95–107. DOI: https://doi.org/10.1515/icom-2022-0008.

10. Lipianina-Honcharenko, Kh., Sachenko, A., Kulyk, V., Savchyshyn, R., Provozin, O., Shchur, S. & Kurpita, L. "Simulation model structure of business processes for a product based on auralization technology". *International Scientific Journal "Computer Systems and Information Technologies*". 2022; (4): 114–120105. DOI: https://doi.org/10.31891/csit-2022-4-15.

11. Cannella, M. "The augmented reality as an instrument for the representation/visualization of architecture". In: Luigini, A. (eds) *Proceedings of the 1st International and Interdisciplinary Conference on Digital Environments for Education, Arts and Heritage. Advances in Intelligent Systems and Computing*. *Springer*, Cham. 2019; 919: 336–344, https://www.scopus.com/authid/detail.uri?authorId=35110465800. DOI: https://doi.org/10.1007/978-3-030-12240-9_36.

12. Boboc, R. G. et al. "Mobile augmented reality for cultural heritage: Following the footsteps of Ovid among different locations in Europe". Sustainability: Switzerland. 2019; 11 (4): 1167. DOI: https://doi.org/10.3390/su1104116.

13. Lee, G. A. Dünser, A. Seungwon Kim & Billinghurst, M. "CityViewAR: A mobile outdoor AR application for city visualization". *IEEE International Symposium on Mixed and Augmented Reality - Arts, Media, and Humanities (ISMAR-AMH.*, Atlanta: GA, USA. 2012. p. 57–64. DOI: https://doi.org/10.1109/ISMAR-AMH.2012.6483989.

14. Cavallo, M., Rhodes G. A. & Forbes, A. G. "Riverwalk: Incorporating historical photographs in public outdoor augmented reality experiences". *IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct*). Merida: Mexico. 2016. p. 160–165. DOI: https://doi.org/10.1109/ISMAR-Adjunct.2016.0068.

15. Cisternino, D., Gatto, C. & DePaolis, L. T. "Augmented reality for the enhancement of apulian archaeological areas". In: *De Paolis, L., Bourdot, P. (eds) Augmented Reality, Virtual Reality, and Computer Graphics. AVR 2018. Lecture Notes in Computer Science (). Springer,* Cham. 2018; 10851. DOI: https://doi.org/10.1007/978-3-319-95282-6_51.

16. Haugstvedt, A.-C. & Krogstie, J. "Mobile augmented reality for cultural heritage: A technology acceptance study". *ISMAR 2012 – 11th IEEE International Symposium on Mixed and Augmented Reality Science and Technology Papers*. 2012. p. 247–255. DOI: https://doi.org/10.1109/ISMAR.2012.6402563.

17. Pettitt, A. & Fuhrmann, S. "The robinson house in the ar-based manassas battlefield national park experience". *i-com*. 2017; 16 (3): 215–222. DOI: https://doi.org/10.1515/icom-2017-0029.

18. Kasapakis, V., Gavalas, D. & Galatis, P. "Augmented reality in cultural heritage: Field of view awareness in an archaeological site mobile guide". *Journal of Ambient Intelligence and Smart Environments*. 2016; 8 (5): 501–514. DOI: https://doi.org/10.3233/AIS-160394.

19. Rainio, K., Honkamaa, P. & Kaisa Spilling. "Presenting historical photos using augmented reality". 2015. Available from: https://www.semanticscholar.org/paper/Presenting-Historical-Photos-using-Augmented-Rainio-Honkamaa/78e983b3b161ccff13ace6be3635df94dae43514. – [Accessed: Feb. 2023].

20. Keil, J., Schmitt, F., Engelke, T., Graf, H. & Olbrich, M. "Augmented reality views: Discussing the utility of visual elements by mediation means in industrial AR from a design perspective. In: Chen, J., Fragomeni, G. (eds). *Virtual, Augmented and Mixed Reality: Applications in Health, Cultural Heritage, and Industry. Lecture Notes in Computer Science (). Springer,* Cham, 2018; 10910: 298–312, https://www.scopus.com/authid/detail.uri?authorId=26425137300. DOI: https://doi.org/10.1007/978-3-319-91584-5.

21. Lipianina-Honcharenko, K., Savchyshyn, R., Sachenko, A., Chaban, A., Kit, I. & Lendiuk, T. "Concept of the intelligent guide with AR support". *International Journal of Computing*. 2022; 21 (2): 271–277. DOI: https://doi.org/10.47839/ijc.21.2.2596.

22. Lipianina-Honcharenko, K., Schauer, S., Sieck, J., Sachenko, A. & Kit, I. "Concept of information system for cultural heritage sites renovation using augmented reality". *Computer Systems and Information Technologies*. 2023; 2: 64–68. DOI: https://doi.org/10.31891/csit-2023-2-8.

23. Gumennykova, T. R., Luhova, T. A., Riashchenko, O. I. & Troianovska, Y. L. "Integration of the process of computer game development with augmented reality in STREAM-education components". *Herald of Advanced Information Technology. Publ.* 2018; 1 (1): 49–61. DOI: https://doi.org/10.15276/hait.01.2018.5.

24. Shih, N.-J. & Wu, Y.-C. "AR-Based 3D virtual reconstruction of brick details". *Remote sensing*. 2022; 14 (3): 748. DOI: https://doi.org/10.3390/rs14030748.

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Застосування доповненої реальності для реновації об'єктів культурної спадщини

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АНОТАЦІЯ

Доповнена реальність є інноваційною технологією, що злиття віртуального та реального світів, створюючи унікальний інтерактивний досвід для користувачів. Хоча ця технологія стала широко відомою лише у середині 2000 років, її потенціал і застосування продовжують стрімко розвиватися, особливо з появою смартфонів та інших мобільних пристроїв, які дозволяють широкому колу користувачів взаємодіяти з доповненою реальністю у повсякденному житті. В області культурної спадщини та туризму, доповнена реальність відкриває нові можливості для відновлення та представлення історичних будівель і місць, які вже не існують або були змінені часом, надаючи відвідувачам можливість бачити і відчувати історичне середовище в його первісному вигляді. Втім, для ефективного використання доповненої реальності у цій сфері необхідно забезпечити точну відповідність між віртуальними об'єктами та реальним оточенням, а також реалізувати навігаційні функції, які допоможуть користувачам легко орієнтуватися у віртуально відновленому просторі. Розробка та впровадження рішень з доповненою реальністю вимагають не тільки технологічної експертизи, але й глибокого розуміння історичного, культурного та соціального контексту об'єктів, що відтворюються. На підставі проведеного дослідження нами розроблено концепцію додатку на базі доповненої реальності для реконструкції та популяризації культурної спадщини. Це включає в себе методики точного відтворення історичних локацій та об'єктів у віртуальному середовищі, а також розробку інтуїтивно зрозумілих навігаційних інструментів для користувачів. Основним здобутком роботи є створення фундаменту для подальшого розвитку технологій доповненої реальності в цій сфері, з акцентом на покращення взаємодії між віртуальними та реальними компонентами, що сприятиме збільшенню залученості аудиторії та підвищенню обізнаності про історико-культурну спадщину. При цьому відкриваються широкі перспективи використання доповненої реальності для культурної спадщини, запропоновані підходи можуть слугувати основою для майбутніх інноваційних проєктів у цій області.

Ключові слова: доповнена реальність; віртуальна реальність; 3D моделювання; реновація; культурні пам’ятки

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