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AUGMENTED REALITY IN THE PRESENTATION OF CITY MONUMENTS: A CASE STUDY OF "BIELSKO-BIAŁA AR GUIDE" MOBILE APPLICATION

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Abstract

Augmented Reality (AR) is one of the modern technologies used for sharing 3D geospatial data. This article presents possible ways of enriching a mobile application containing information about 50 objects located in the city of Bielsko-Biała with an AR functionality. The application was created in two programs: Android Studio and Unity. The application allows to get to know historical objects of the city, encourages to visit them by adding virtual elements observed in the background of a real-time camera image from a mobile device. The article presents the statistics of the application usage and the results of a survey conducted among a group of testers. Feedback from application testers confirms the validity of using AR technology in the application.

ROZSZERZONA RZECZYWISTOŚĆ W PREZENTACJI ZABYTKÓW MIASTA: APLIKACJA „BIELSKO-BIAŁA PRZEWODNIK AR", STUDIUM PRZYPADKU

Słowa kluczowe: Rozszerzona Rzeczywistość, mapy interaktywne, Android, Unity

Abstrakt

Rzeczywistość Rozszerzona (Augmented Reality – AR) jest jedną z nowoczesnych technologii wykorzystywanych do udostępniania danych przestrzennych 3D. W artykule przedstawiono możliwe sposoby wzbogacenia aplikacji mobilnej o funkcjonalność AR. Aplikacja zawiera informacje o 50 obiektach zlokalizowanych na terenie miasta Bielska-Białej i została stworzona w dwóch programach: Android Studio oraz Unity. Aplikacja pozwala na poznanie zabytkowych obiektów miasta oraz zachęca do ich zwiedzania poprzez dodanie wirtualnych elementów obserwowanych w czasie rzeczywistym na tle obrazu z kamery urządzenia mobilnego. W artykule przedstawiono statystyki użytkowania aplikacji oraz wyniki ankiety przeprowadzonej wśród grupy testerów. Informacje zwrotne od testerów aplikacji potwierdzają zasadność zastosowania technologii AR w aplikacji.

1. INTRODUCTION

Changing user requirements, exponential growth of spatial data, widespread use of smartphones, access to the Internet, and other factors caused the need for new means of communication, data transfer and presentation in geoinformatics. These means include, but are not limited to: Virtual Reality (VR) (Shehade and Stylianou-Lambert 2020), Augmented Reality (AR) (Cejka et al. 2021), Interactive Cartography (IC) (Medyńska-Gulij, Forrest, and Cybulski 2021), Volunteered Geographic Information (VGI) applications (Norman, Pickering, and Castley 2019), new methods of cartographic presentation, i.e. heat maps (Netek, Pour, and Slezakova 2018). As early as in 1994, Miligram and Kishino noticed the trend of virtualizing information transmission and defined differences between VR and AR by setting them on a continuous Mixed Reality axis (Milgram and Kishino 1994). This axis starts at a real object (Reality) and ends at its full virtual representation (VR). Augmented Reality, together with Augmented Virtuality (AV), are placed between these extremes and can be classified as Blended Reality. What distinguishes AR from AV is that in AR the primary state is reality to which virtual elements are added (Prasad Mohanty and Goswami 2021). Mobile applications enriched with AR modules are currently very popular and can be used in education (Bharath et al. 2021), medicine (Kan Yeung et al. 2021), spatial and urban planning (Schranz, Urban, and Gerger 2021), cultural heritage studies (Hincapié et al. 2021), agriculture, and many other fields. The use of AR and VR is particularly valuable for the presentation of spatial data (Sztwiertnia et al. 2019; Barazzetti et al. 2015; Halik and Medyńska-Gulij 2017) and for educational purposes (Woods et al. 2016; Hedenqvist, Romero, and Vinuesa 2021).

The real heyday of AR technology came with the development of smartphones. The increased recognition of AR in society has been particularly influenced by one mobile application: Pokémon GO (Kamel Boulos et al. 2017). In this app, players catch Pokémons in the entire world (entire city) that is an area of game, interact with them and earn points. The players see a map (modified Google Maps view) on their smartphones which presents the real world expanded with game elements. The application takes advantage of the fact that it has become a standard to equip smartphones with GNSS receivers and other sensors such as compasses, gyroscopes, accelerometers, cameras. It was not the first game of this type, but thanks to a very recognizable brand it achieved a big success. It is worth noting that to play Pokémon GO it is only necessary to install the app on a smartphone, and no additional fees or devices are required to enjoy the game. This fact has significantly contributed to the popularity of the application. Pokémon GO has established the global trend of using AR technology in smartphones.

Another trend in the use of AR is the construction of workstations, devices, and applications adapted specifically to this technology and allowing to maximize the benefits of augmenting reality with virtual elements. An example of such a construction is the AR Sandbox (Kundu, Muhammad, and Sattar 2017). It consists of a sandbox, projector, Kinect sensor, and a computer unit with dedicated software. The sandbox is used to visualize a hypsometric map in real time. The map is projected onto the sand which represents terrain. The application also allows to observe how virtual water behaves on the projected terrain. The AR sandbox is often used to present changing terrain in popular science exhibitions (science parks), as well as in military command centers (Zocco et al. 2015). Although the application is made available under a free license, it is used mostly in large institutions due to high hardware requirements. The authors of the AR Sandbox software reported that they were aware of 844 installations of the software worldwide in September 2019 (Kreylos 2021). Despite this relatively small number of installations, the AR Sandbox has been seen by millions of people at science parks, science festivals and other such events.[1]

The effectiveness of using AR technology is measured not only by the number of app users but also in traditional research studies. Putra et al. studied the usefulness of Mobile-Augmented Reality (MAR) technology in solving complex problems while using a digital encyclopedia (Putra et al. 2021). In qualitative research, they confirmed that using MAR enhanced students' decision-making skills. Hedenqvist et al. investigated the usefulness of AR applications in understanding the torque phenomenon among students enrolled in a mechanics course (Hedenqvist, Romero, and Vinuesa 2021). The first tests showed better understanding of the phenomenon among students using AR compared to those in a control group. Woods et al. studied the impact of using the AR Sandbox in learning geomorphology (Woods et al. 2016). They noted the positive impact of using such a didactic innovation on the learning process.

The aim of this article is to present the possibility of using Augmented Reality in providing information about the monuments of Bielsko-Biała. The mobile application was created by combining several AR

[1] In Kraków, the AR Sandbox is operated by the Faculty of Mining Surveying and Environmental Engineering of the AGH University of Science and Technology

functionalities, and it allows one to explore the city's history while playing an outdoor game. The application was made available in the Google Play store (GP).[2] The subsequent sections of this paper present data and technologies used, operation of the application, statistics of users from the GP store, feedback from testers, and a summary with conclusions.

2. APPLICATION OBJECTIVES[3]

The Android operating system was chosen as the operating environment for the application due to its predominant market position (Majchrzyk 2021). Android's lead over iOS has been growing steadily for the past two years and accounted for 24 percentage points of mobile market share in January 2021. While developing the application, its two versions were created. The only difference between them is that one of them does not have the AR functionality. It was created for comparison purposes (see sections 4 and 5) and to allow people with less advanced devices to benefit from the descriptions of monuments in Bielsko-Biała. In the remainder of this paper, the app with the AR functionality will be described, unless clearly stated differently.

The first step while designing the application was to create its interface in Android Studio, implement Google Maps and import tables with data about objects (Table 1). For each object, a historical photo presenting its appearance in the past was obtained. The first table contained: object ID, name, description, information about the source of the archival photo. The objects were divided into three groups: churches, streets and other monuments. These groups constituted 3 categories in the application menu class. The second table included: object ID, name, and geographical coordinates (Table 2). Even though the location of each object was known, it was necessary to acquire their coordinates in the field using the ArcGIS Collector mobile application. These coordinates do not represent objects as such, but the locations from which historical photos of the objects were taken. A Xiaomi Redmi 9 mobile device was used to measure the coordinates. For all objects, a current photograph was taken from possibly the same perspective as a corresponding archival photograph. This made it possible to highlight changes over time.

By obtaining the coordinates for each object, it was possible to create map markers for them in corresponding locations on an interactive Google Map. A total of 50 objects were presented in the application (Fig. 1)

From the application's main menu (Fig. 2a), the AR view of the monuments in Bielsko-Biała can be accessed in two ways. The first one requires selecting a monument from a list of churches, streets, or other monuments, and the second one is based on selecting a monument on a map with Google Maps base map. In the first way, after selecting one of the categories: "Churches", "Monuments" or "Streets", a scrolling window with annotated historical photos is displayed (Fig. 2b). Thanks to such an application design, users not familiar with Bielsko-Biała can select objects of interest based on their photos. After clicking on a selected image, the app displays another window containing a historical photo of the given object, its current photo and four buttons at the top of the screen. The functionalities of the buttons are as follows:

- enable the AR mode,
- switch on the interactive Google Map with a map marker of the object (Fig. 2d) – other objects in the vicinity are visible on the map,
- display the object's description,
- enable speech synthesizer for description reading.

It is also possible to access information about the objects by selecting the "Map" subcategory from the main menu (Fig. 2c). The interactive Google Map shows all objects in the vicinity (Fig. 2d). After clicking an object, its current photo and name are displayed in a balloon (Fig. 2d). After another click, the user is redirected to the object's page with its historical photo and a short description.

In the main menu there are also "Scoring" and "About the application" subcategories. The first one redirects the user to a list of visited and unvisited objects. Visiting each object means one point to be scored. In the "About the application" subcategory, there is a short description of how the application works.

[2] The application is available in two versions. With AR functionality: https://play.google.com/store/apps/details?id=com.depresja3.depresja3 and without AR functionality: https://play.google.com/store/apps/details?id=com.depresja3light.depresja3light.

[3] Sections 2 and 3, and the application were created on the basis of the engineering thesis entitled "The use of augmented reality in the multitemporal presentation of the monuments of Bielsko-Biała" (Department of Integrated Geodesy and Cartography, AGH University od Science and Technology in Kraków, supervisor – Stanisław Szombara, PhD).

Table 1. Sample record for a single object included in the table with descriptions and archival image sources
Tabela 1. Przykład rekordu dla jednego obiektu z tabeli zawierającej opisy obiektów i źródła zdjęć archiwalnych

OBJECT ID	NAME	DESCRIPTION OF THE OBJECT	SOURCE OF HISTORICAL PHOTO
3	**Zamkowa Street**	Zamkowa Street as seen from Żwirko and Wigura square in 1910. The buildings visible on the right, as well as those deep behind the tallest building on the left did not survive the "Great Destruction" in 1974, during which the street was turned into a four-lane artery	(Zamkowa Street as seen from Żwirko and Wigura square) (Ćwikowska-Broda and Ćwikowski 2008)

Table 2. Sample record for a single object included in the table with geographic coordinates
Tabela 2. Przykład rekordu dla jednego obiektu z tabeli zawierającej współrzędne geograficzne

OBJECT ID	NAME	LATITUDE [°]	LONGITUDE [°]
3	**Zamkowa Street**	49.82025501	19.04414020

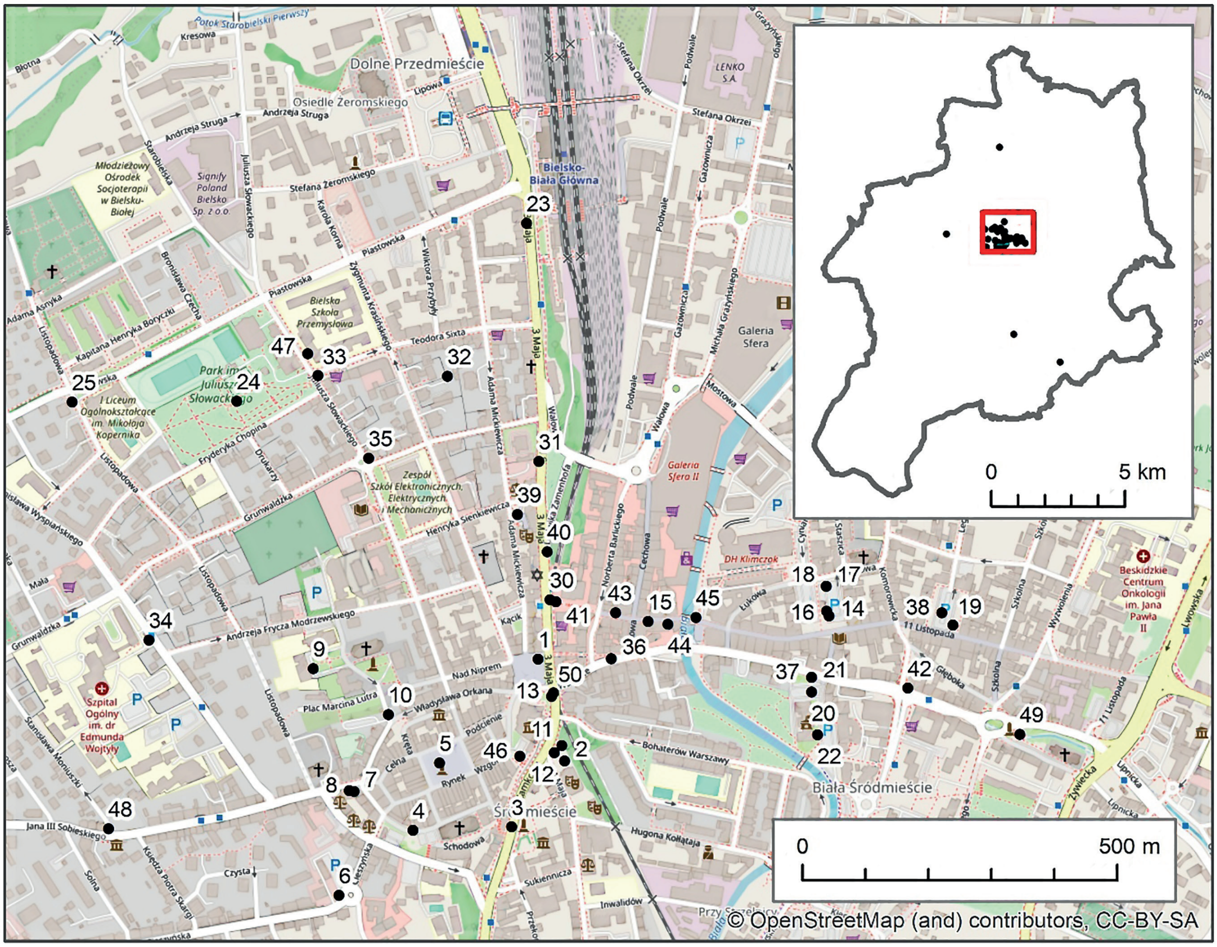

Fig. 1. Location of the objects in the center of Bielsko-Biała and with reference to its administrative border
Rys. 1. Rozmieszczenie obiektów w centrum Bielska-Białej oraz na tle jej granicy administracyjnej

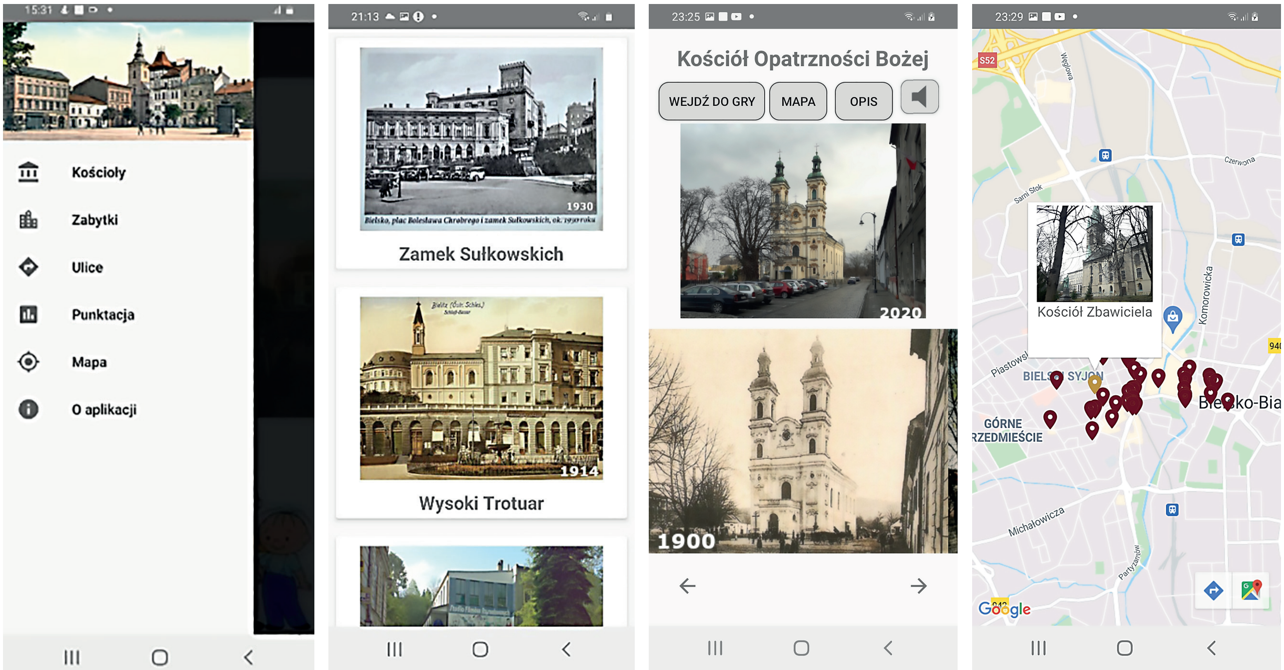

Fig. 2. Different sections of the application: a) list of subcategories from the main menu, b) list of objects in the "Monuments" subcategory, c) window of one object from the "Churches" category, d) location of the object on the Google Maps base map
Rys. 2. Widoki stron aplikacji: a) lista podkategorii z menu głównego, b) lista obiektów w podkategorii „Zabytki", c) okno obiektu z kategorii „Kościoły", d) położenie obiektu na podkładzie mapowym Google Maps

3. AUGMENTED REALITY IN THE APPLICATION

The Augmented Reality module was created in Unity using Vuforia and ARCore plugins. The user panel was created with Unity's default tools. The most significant virtual reality augmentation is a virtual cube with a superimposed texture of an archival photo of the object. A C# script was written for the cube to calculate the distance between the current location of the device and the object's location (Table 2). In order to connect Android Studio and Unity, it was necessary to export the Unity project as a 'jar' library which is initialized when the "Enter game" button is pressed (Fig. 2c). It causes the transmission of coordinates and name of the selected object, and the user's position to Unity. After running Unity, the user is in the Augmented Reality mode (Fig. 3). The name of the selected object, GNSS signal reception status, and distance to the historical object are displayed on a screen in real time, with a camera image obtained from a mobile device in the background. If the distance condition is met (<30 m), the virtual cube is activated. The Unity script textures the virtual cube with a historical photo of the object in question. From the screen of Unity showing an Augmented Reality scene for a selected historical object, the user can return to the main application. Information on visited objects is transmitted to the main application by the AR module for scoring updates.

The activation of the virtual cube depends on geolocation data acquired from a GNSS receiver. The accuracy of these receivers can vary depending on the version or model of the device (Maciuk 2015). For the same device, the virtual cube appears in different locations depending on the instantaneous accuracy of the smartphone's GNSS device (Fig. 3). For this reason, it is impossible to embed the virtual object always in exactly the same location (also for different mobile devices). Thus, the virtual cube appears when the user approaches the object of interest within a distance of 30 m from the location defined by the coordinates in Table 2. The Augmented Reality module is only supported by devices running Android 7.0 or newer (API minimum 29 which supports the ARCore plugin. Fur-

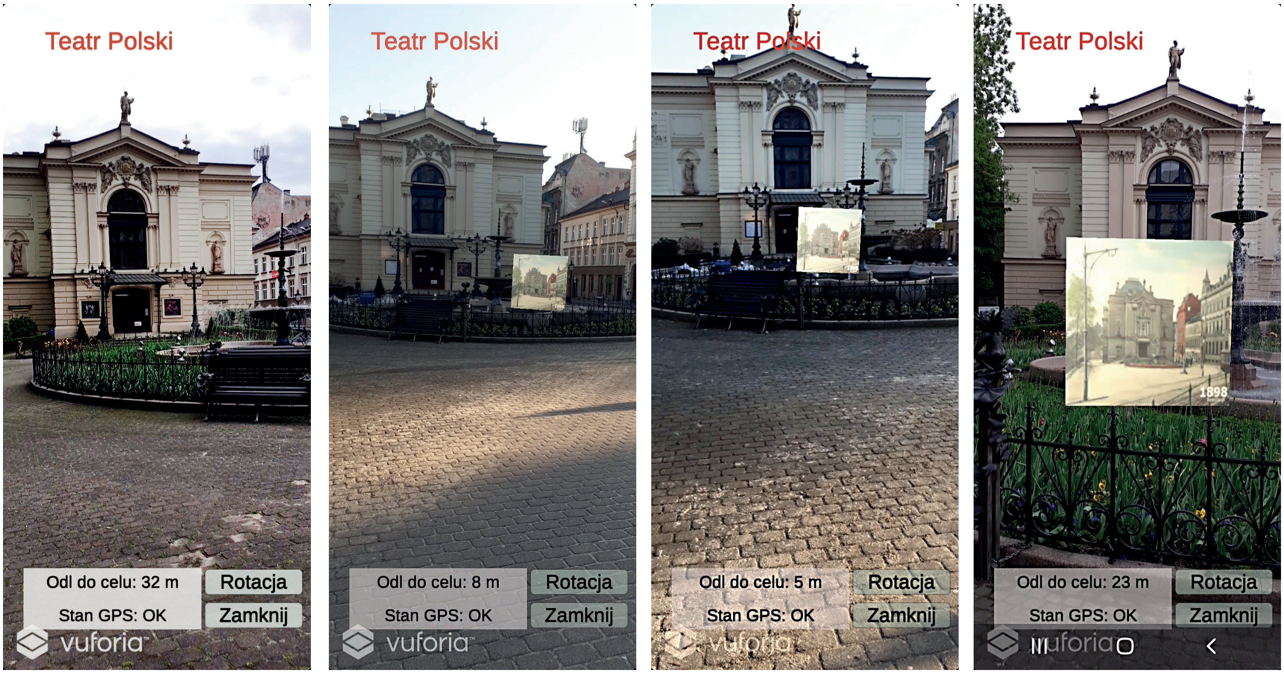

Fig. 3. AR view of one of the objects. Visible different distances to the target with similar actual distance (influence of a GNSS receiver's inaccuracy in the mobile device)
Rys. 3. Widok AR jednego z obiektów. Widoczne różne odległości do celu przy podobnej odległości rzeczywistej (wpływ niedokładności odbiornika GNSS w urządzeniu mobilnym).

thermore, the mobile device should be equipped with IMU sensors (i.e. gyroscope and accelerometer). For devices that do not meet these requirements, it is not possible to install the application in the version with AR functionalities.

4. APPLICATION USAGE STATISTICS

Figures 4 and 5 show usage statistics for the two versions of the app. Since the application was made available in two versions to 5th August it has been down-

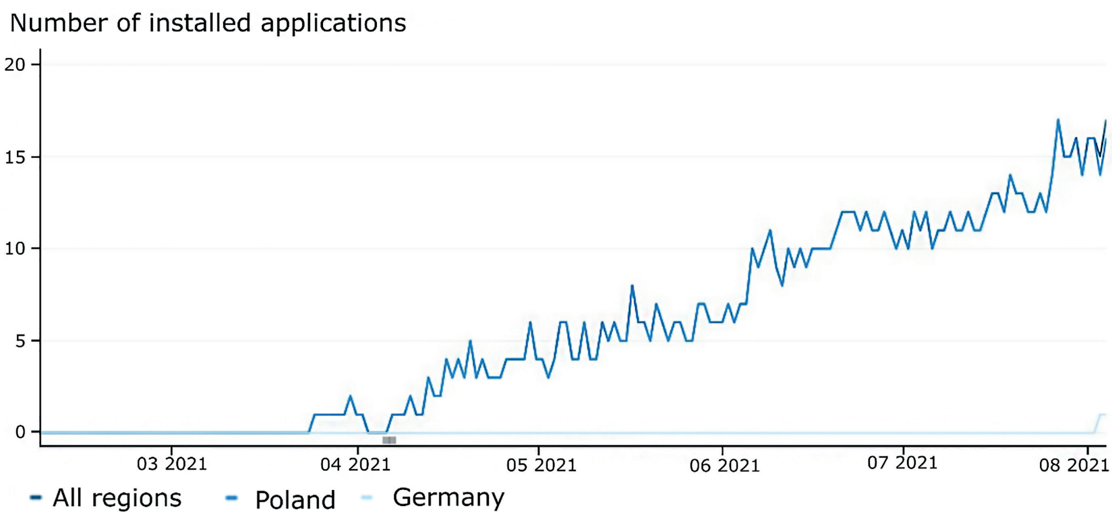

Fig. 4. Number of installed applications in the version with AR functionalities
Rys. 4. Liczba użytkowników aplikacji w wersji z funkcjonalnościami AR

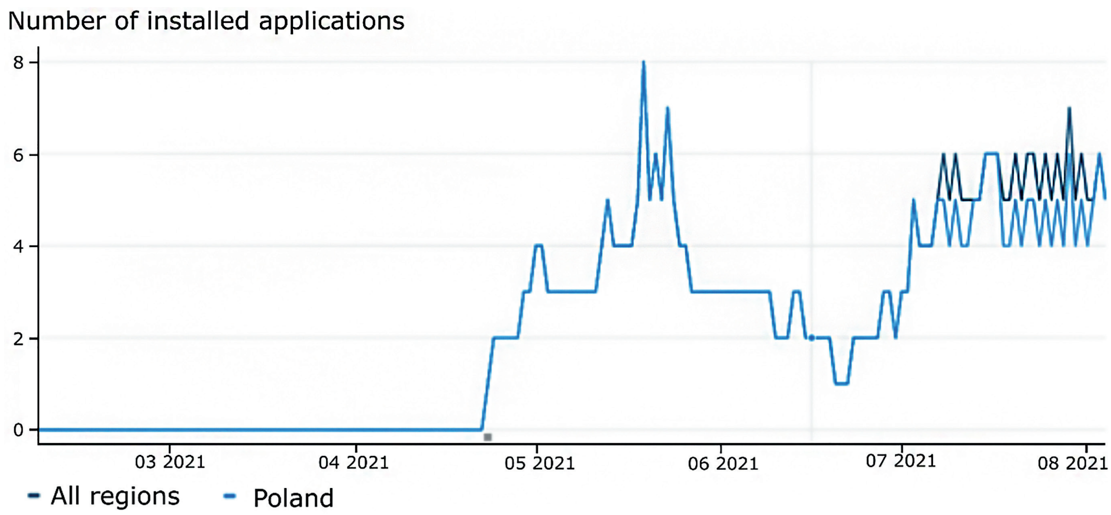

Fig. 5. Number of installed applications in the version without AR functionalities
Rys. 5. Liczba użytkowników aplikacji w wersji bez funkcjonalności AR

loaded and installed by 51 users. The version with AR was downloaded 28 times and the version without AR was downloaded 23 times. The graphs clearly show that the app with AR functionalities keeps users for longer and the app without AR loses its users.

5. SURVEY RESULTS AMONG A GROUP OF TESTERS

In order to qualitatively test the usefulness of the application for exploring Bielsko-Biała, and to test the attractiveness of the Augmented Reality functionality, a questionnaire consisting of 12 questions was prepared. Most of the questions used a five-point Likert scale (Likert 1932). The questions are presented in Table 3, and the summary of responses is shown in Table 4.

6. DISCUSSION

Augmented Reality is becoming increasingly popular, which is associated with the spread of mobile devices that can support AR applications and greater public awareness of the existence of this technology. The application presented in the article is part of this trend.

Table 3. Questions and possible answers for the application testers
Tabela 3. Pytania i możliwe odpowiedzi dla testerów aplikacji

Number	Question	Possible answers
1	How often do you move around the area of Bielsko-Biała covered in the application?	Every day; Several times a week; About once every week/two weeks; About once every month/two months; Less often
2	What sources of information do you usually use while visiting the city?	Local guide; Mobile application; Information boards; Website entries
3	Which scheme did you find more intuitive for navigating the app?	Selecting one of the subcategories: “Churches”, “Monuments”, “Streets” from the main menu; Selecting the subcategory “Map” from the main menu
4	Do you know what Augmented Reality is?	Yes/No
5	Did the AR module help you better remember the former appearance and approximate location of the object?	Likert scale: Definitely yes; Rather yes; Don’t know; Rather not; Definitely not

Table 3 cont. / Tabela 3 cd.

Number	Question	Possible answers
6	Did collecting points for visiting historical objects motivate you to visit other corners of the city? (refers to the app with AR)	Likert scale
7	Did the AR module in the app make you more engaged and help better remember a particular object?	Likert scale
8	In your opinion, is the object's location indicated accurately enough, and can the object be properly seen during the game?	Likert scale
9	How much time (approximately) did you spend exploring the city with the app?	Number of hours
10	How many points did you get?	Number of points
11	Which application (with/without the AR module) would you recommend to your friends?	Application with the AR module; Application without the AR module
12	Would you encourage other visitors to explore Bielsko-Biała using AR?	Likert scale

Table 4. Survey results for the application testers. Question 5, 6, 7, 8 and 12 used the same scale
Tabela 4. Wyniki ankiety dla testerów aplikacji. Pytania 5, 6, 7, 8 i 12 miały tę samą skalę odpowiedzi

Question	Answers
1	Daily: 1 Several times a week: 2 About once every week/two weeks: 2 About once every month/two months: 0 Less often: 1
2	Local guide: 1 Mobile app: 1 Information board: 3 Web posts: 1
3	Selecting one of the subcategories: Churches, Monuments, Streets: 5 Selecting the subcategory Map: 1
4	Yes: 6 No: 0
5	Likert scale: Definitely yes: 1 Rather yes: 4 Don't know: 0 Rather not: 1 Definitely not: 0
6	Likert scale: 4 2 0 0 0
7	Likert scale: 1 0 4 1 0
8	Likert scale: 1 2 3 0 0
9	3; 2; 3; 4; 2; 2 – on average 2.6 h
10	21; 26; 4; 39; 30; 17 – on average 22.8 points
11	With the AR module: 5 Without the AR module: 1
12	Likert scale: 3 2 1 0 0

Although the application was not promoted in any way in Google Play store, it was downloaded and installed by dozens of people. Information about its existence appeared only on geoforum.pl and Facebook pages of the Faculty of Mining Surveying and Environmental Engineering of AGH UST. It can therefore be said that those people who have benefited from it are not accidental persons. The application was tested by a group of 6 testers. The results of the survey should be treated as indicative, due to the small sample size.

The survey was completed by students aged 20–25, most of whom frequently stay in Bielsko-Biała. The respondents were familiar with the concept of Augmented Reality. Most of the responses given suggest that the reception of AR functionalities was positive. Only to questions 7 and 8 the respondents answered that they do not know whether AR functionalities result in increased engagement and whether the indication (location) of the object in the AR mode is accurate enough. These responses could be affected by the need for self-assessment or the lack of familiarity with the basics of satellite navigation. The respondents spent an average of more than 2 hours using the app and scored 23.8 points on average. The application appeared to be recommendable and its version with the AR functionality encouraged people to share it with others. The answers also confirmed the assumption that the user experience is highly related to the quality of the smartphone on which the application is run. The lack of standards for AR functionalities and several hundred mobile devices on the market make it difficult to develop a universal application.

The application is not equipped with any functionality that could keep users for a longer period of time, such as a user-versus-user ranking. For this reason, when the user leaves Bielsko-Biała, it is usually removed. The AR version of the app is more popular, even though the number of supported devices is much smaller (500 devices) compared to the version without AR (12,083 devices). The highest interest in the application and most installations occurred during the holiday season.

Despite the disadvantages mentioned above, the application does the job as a modern carrier of geoinformation data. With relatively simple and free programming tools, interactive maps in mobile tourism applications can be significantly enhanced with Augmented Reality. Free tools that were used while creating the application are not optimized for the use of AR functionalities on mobile devices in the field. Numerous difficulties were associated with the need for connecting Unity and Android Studio and enabling bilateral data exchange. The surveys conducted, conversations with the users, and statistical analyses allow for making future plans concerning the implementation of AR functionalities in other applications presenting city monuments in an attractive way.

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