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Acceptation of the Developed Mobile Virtual Reality Visualisations of 3D Objects from the Area of the Silk Road

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ABSTRACT

The paper presents a process of testing a created virtual reality application for displaying the "Hujra", a room for students of the 17th century madrassa in the area of the Silk Road, together with interactive objects. The designed 3D objects had sufficiently small file sizes to be introduced into virtual reality, and the fully mobile application worked effectively using smartphones within the price group available to the average user. The application was presented to a group of students and researchers from Kyrgyzstan. In addition, objects not belonging to the Islamic culture were introduced into the students' room. Pilot tests confirmed the usefulness of the proposed solution of 3D modelling. Interviews with the participants of the experiment and the results of a survey showed that the virtual reality application was a very attractive form of presentation, especially for people belonging to Generation Z. The combination of the complexity of the project and its high availability via smartphones was considered a successful solution by those questioned.

Keywords: mobile application; virtual reality; cultural heritage; Silk Road; generation Z; virtual museum

INTRODUCTION

The development of 3D and 2D computer technologies (hardware and software), as well as mobile technologies, makes it possible to put into practice the process of digitisation of cultural heritage objects and use them in many different way.

Firstly – it allows for digital archiving of historic buildings threatened with destruction due to their age, condition or the conditions in which they are located. For example, as a result of the fire of the National Museum of Brazil in Rio de Janeiro in 2018, 90% of the local resources were irretrievably lost [1]. The war in Syria led to the ruin of, among others, excavations in the ancient city of Palmyra [2, 3]. We cannot predict such phenomena and cannot always counteract them. Digital archiving allows, at least to some extent, to protect monuments from complete annihilation and oblivion.

Secondly – the use of 3D technology makes it possible to reach young people. Representatives of generation Z (according to various sources, the generation born after 1990 and before 2010), the so-called "Digital natives" appreciate the possibility of not only consuming digital content, but also using the interaction layer. This situation also applies to cultural heritage objects that can be transferred as 3D models to the VR world.

Thirdly – the popularisation of digital 3D technologies allows for the democratisation of access to cultural goods of people with different social status (resulting from belonging to a cultural or religious environment), economic status (the possibility of traditional visits to historic places), political status (the possibility of free travel). Digital worlds of cultural goods also make it possible to counteract the exclusion of people with various degrees of physical and mental disabilities.

Fourthly – digital objects presented with the use of various available technologies allow for continuous access to educational and cultural content (independence from the opening time or the capacity and number of visitors). In times of the ongoing COVID19 pandemic, presentations in the form of virtual museums (VMs) are conducive to maintaining safety, social distance and eliminating the need to travel.

Therefore, the process of reconceptualisation [4] of museology requires the creation of attractive and interesting visualizations of museum artefacts and historic architectural objects. The term of museology reconceptualisation is understood as supplementing the traditional exhibition by introducing additional exhibitions, which, for example, allow to get to know the copies of museum artefacts by touching them (not only for the blind), to simulate the time of events by the use of inter-active touch monitors, to get immersed in digital space through the use of VR technology. A well and methodically created digitisation of museum collections permits (1) the creation and sharing of digital archives, and (2) the modernisation of the offer of contemporary museology through the use of modern visualisation technologies, such as virtual reality (VR), augmented reality (AR) or mixed reality (MR). The authors already carry out this type of activity. Employees of the Department of Computer Science of the Lublin University of Technology (Poland) have been cooperating with Samarkand State University (Uzbekistan) for several years in the area of using 3D computer technologies in the area of broadly understood cultural heritage, museology, protection of architectural objects [5], as well as the reconstruction of damaged museum objects [6].

The present article pursues the following goal:

- Verification of the quality of the solutions used in the construction of the "Hujra" application (low-cost, fully autonomous and mobile interactive application that works properly in the VR environment) by conducting pilot studies in Central Asia in in situ conditions.

By the term low-cost solution the authors mean that to display the VR world a smartphone belonging to the mid-price segment will be used, and the phrase completely autonomous solution means that to render scenes in VR the smartphone will not be connected to a computer station, will not use cloud resources via internet communication or be connected to an external source of water.

The created application "Hujra" introduces the user to the pupils' room, where there are 7 objects of equipment characteristic of Islamic culture (lauch, book, table, turban, carpet, two kilims) and 2 objects from outside of this culture (sculpture and painting).

BACKGROUND

Virtual models in the context of creating digital museum exhibitions were introduced in 1991 by Tsichritzis and Gibbs in a speech presented at the Pittsburgh conference [7]. In [8], the authors describe their own approach to designing and constructing a VR museum, but this is an era of solutions that do not use glasses and the experience of these activities is not fully transferable to modern times. Among the methods of creating digital 3D objects, they recommend manual modelling when the object consisted mainly of geometric forms. Strategies for designing VR applications related to cultural heritage, describing the guidelines for the development of VR systems and presenting their own stereoscopic MNEME system (which does not correspond to VR systems in the modern sense of the term) are presented in [9]. In [10], the authors point out that in VR technologies three components should be properly balanced: interaction, immersion and imagination. The present Virtual Culture Museum application was built on a server solution and is not mobile. A description of the use of modern computer technologies to create internal serious games enabling the transfer of knowledge in the field of cultural heritage by creating the "El Greco's Travels and Artwork" application is presented in [11]. In [12], on the other hand, a description of designing virtual museum exhibits on the example of the "Museum of the Bruttians and the Sea" of Cetraro (Italy) is shown.

An example of an interactive archaeological exhibition created in VR with the use of Oculus Rift, connected with the Kinect controller as an element of interaction and a laptop which, through the Unity environment, supervised the entire system with objects made using 3D scanners, is described in [13]. Increasingly, VR technology is used to prepare virtual tours around historic buildings [14].

In [15] the authors describe the classification of application-oriented VR installations that can be used in the area of cultural heritage, and practical comments on the creation of VR exposures in the form of a procedure consisting of 6 steps are found in [16]. In [17], the authors indicate that the use of modern computer technologies enables the acceleration of the creation of a network of museum units that represent a common geographical and cultural area, as well as various centres with collections on the same subject. Study [18] presents an analysis of 3 VR projects in museums, paying attention to the way in which VR applications in museology contributed to the development of cooperation between the world of art and technology. In addition, attention was paid to the economic and marketing aspects of such an undertaking, and thus building the museum brand through the implementation of VR technology. Examples of VR applications for mobile platforms can be found in [19] – studying the possibilities of teaching music to a group of children aged 10-11 with a multi-platform mobile application called VR4EDU, [20] – description of a low-cost mobile platform (based on Samsung Gear VR Innovator Edition and a Sam-sung smartphone) intended for research on the impact of the immersive environment on the efficiency of the teaching process (research results not included). An interesting application of VR techniques is teaching intercultural competences [21, 22]. Study [21] contains a description of attempts to develop a game based on the creation of a virtual character with predefined cultural characteristics, which will react to the user's behaviour. In [22], the digital Terf platform was used for virtual collaboration of students from different countries so that the experiences gained there could be transferred to the real world. The way of acquiring intercultural knowledge through activities in the virtual world by people related to the healthcare environment is presented in [23, 24]. The method of assessing the effects of virtual transcultural training by applying Hofstede's cultural dimensions using the "SIMPLE" methodology is described in [25], and in [26], an innovative methodology for assessing gradual changes in the acquired intercultural competences was used in [26].

Researchers are more and more willing to implement VR in the field of museology. In [27] the proprietary MARAT (Mobile Augmented Reality Authoring Tool) device was proposed, which allows mobile creation of complex interactive content in AR in WYSIWYG mode. Also in [29], a proposal of the VIRTUE system for creating 2D and 3D static and dynamic museum exhibitions was included. However, in [30] Viking VR offers a virtual VR exhibition enriched with sounds from the 9th century Viking camp. A prototype of a virtual museum of consumer technologies was created by researchers in [31], who named the prepared solution JanusVR. In [32] a correlation was noticed between the increase in experience in VR and the use of visualisation algorithms – painting and artistic style algorithms. On the other hand [33] investigated the impact of VR and AR on the impressions of tourists visiting the Geevor museum, while pointing to the issues of experimental economy.

The development of modelling technology requires the design and use of increasingly powerful tools to create information-rich interactive 3D environments. Therefore, in [34], the integration of the virtual environment with HDRI panoramic photography (360°) was used as a new form of photorealistic immersive visualisation. The Imperial Cathedral of Königslutter was laser-scanned and then photographed in a panoramic view. Both data sets were combined thanks to simple mechanics developed in the native programming language Unreal Engine 4 (UE4) and the end result was tested in the HTC Vive Pro VR system. An interesting immersive approach was also presented in [35], where researchers integrated data from 3D models of cultural heritage sites in two game engines, Unity and Unreal. [36] presents the conversion and adaptation of the virtual historical 3D model of the city of Duisburg to VR applications in combination with digitisation for Google Earth. The whole is carried out by the scope of interactive VR cartography.

The high quality of VR applications for mobile devices affects the user experience. Therefore, in [37] the performance analysis of VR application rendered locally on the phone and remotely – thanks to the server and wireless network (802.11ac standard) was carried out. Based on the results of the analyses, FURION was proposed – a VR framework to support high-quality VR applications over a wireless network (Wi-Fi) with a delay of less than 14 ms with a performance of 60 frames per second. The issues of high quality, low latency in the wireless network (for 4K resolution) and rendering were also analysed in [38], proposing the Remote VSync Driven Rendering technique based on parallel rendering and streaming. Another approach to scene rendering is found in [39], describing the FlashBack project for weaker HMD VR mobile devices, which avoids real-time rendering by using image precomputation and buffering. FlashBack renders static and dynamic scenes with animated objects, allowing, among others: lower latency, higher frame rate (compared to local rendering for mobile devices). In [40] the Flare system was proposed (streaming 360° movies to mobile devices) giving a max. of 18-fold improvement in quality on Wi-Fi, reduction of bandwidth to 35% and improvement of video quality in LTE network to 4.9. A very interesting approach to high-quality sensory immersion is presented by researchers in [41], i.e. CloudVR. It is a system that offers safe acceleration of virtual VR activities in the cloud. In addition, it focuses on panoramic rendering, rendering optimisation and dynamic object placement. The system provides improved throughput, lower latency and good graphics quality (multi-resolution rendering).

Researchers appreciate VR, AR and MR more and more, anticipating future application directions in the field of cultural heritage [28] – not only for the visualisation of museums, but also old cities, monuments, excavations or the reconstruction of damaged cultural objects.

The literature research shows that the subject of creating mobile applications for smartphones, commonly available to users, for sharing digital museum resources in VR technology, is not overly described and implemented. This is mainly due to technical challenges including, among others: striving for high-quality visualisation on a mobile device, minimising image generation delays, ensuring good data streaming as well as correct rendering with its optimisation to relieve the entire process of creating virtual space. The previously presented works of researchers [37–39, 41] largely focus on technical problems, the omission and unresolved status of which will not allow for quick and easy implementation of mobile VR applications in museology, where graphic details and accurate mapping are important, e.g. objects, pictures. It can be seen that the subject matter is developing at the fastest rate possible, despite the dominance of desktop VR applications in the area of cultural heritage.

However, the available works on the implementation of VR technologies in the area of broadly understood cultural heritage do not pay attention to the geographical context. What is a technological standard, e.g. for most European countries (devices used, wireless network availability, data transfer speed, data processing availability in cloud computing, low costs in relation to the average income of residents) is not a rule in other regions or countries. Such a situation occurs, inter alia, in many places in the area of the Silk Road in the countries of Central Asia [42, 43]. Therefore, the solutions used to create applications intended for VR technology should be designed and prepared to be completely autonomous and cheap. The authors of this work exclude solutions intended for installation on specialised VR devices and systems, recognising mobile VR as technologies more conducive to the democratisation of access to educational and cultural content. In addition, it was assumed that the devices used, such as a smartphone, will not have to use a connection to a computer or a cloud-based system to parallelise and accelerate the calculations.

PILOT STUDIES FOR APPLICATION

Application description

The created "Hujra" application based on VR technology allows to enter the students' room (showing a 17th century interior), walk around it and visit the objects placed there (Fig. 1). The application provides 3D models of the exhibits selected by the employees of the museum in Samarkand (Uzbekistan) and 2 additional ones that do not belong to the Islamic culture. The 3D models were appropriately simplified and by programming the interaction between them and the user, they could be activated, which made it possible to display billboards with information about the object. The designed application was completely autonomous and prepared in such a way that the VR presentation can be made on a smartphone-type device. By a completely autonomous solution, the authors understand a case that does not require the use of additional devices (workstations) or cloud systems (Internet connection) to perform the necessary calculations to display the rendered 3D scenes, and does not require the use of external power sources.

The "Hujra" application was tested during the "3D Technology in Cultural Heritage" science seminar at the Kyrgyz State Technical University in Bishket (Kyrgyzstan) (Fig. 2). The duration of

Fig. 1. View of the scenes from the "Hujra" application

the entire seminar was limited to 4 hours (including breaks). During the seminar [44], the last of the five presentations concerned the presentation of the use of VR technology in the area of creating museum exhibitions. Thus, potential participants of the research obtained the necessary information about the devices used, how to operate them, about the available methods of interacting with the set objects in the room (the texts appearing on the billboards were prepared in English). Such setting of the seminar program made it possible to conduct research immediately after its completion with the participation of people who wanted to participate in them. These people were provided with additional information on the purpose of the research, as well as informed about the possible effects of experiencing immersion after entering the VR environment. Participants could move around in the hujra room and watch the exhibits prepared. The research was qualitative and quantitative. After the VR trip, information was collected via the designed questionnaire and loose opinions of individual participants about the prepared application. The tested application was running on a Samsung Galaxy S6 devices – 5.10" display with 1440x 2560px resolution, 3GB RAM, system Android 7.0.

METHODOLOGY

The purpose of the research was to verify the design assumptions for the preparation of an autonomous mobile application. The authors wanted to check:

1. whether the quality of the rendered students' room and all objects arranged in it will be satisfactory in terms of realistic appearance,
2. whether the effect of a user's immersion during the VR session will be felt by him,
3. whether the method of providing detailed information about the objects placed in the room is satisfactory,
4. whether the low-cost solution made in remote collaboration resulted in a satisfactory end product.

We had preliminary information from the seminar organisers that there would be no more than 50 people in the room and that there would be students, doctoral students and academic teachers of both sexes. Thus, the authors did not have the opportunity to select people for the research sample in a balanced way, the more so that it was clear from the interviews with the organisers

Fig. 2. Pilot studies of the application: (A) participants of the seminar, (B) presentation of the use of the set, (C, D) responders

of the seminar that there was no gender parity among students and employees.

The research group consisted of scientific seminar participants: students (17 people – Generation Z (65%), 10 women and 7 men; age 21–24) as well as research and teaching staff (9 people (35%), 7 women and 2 men; age 28–63).

The questionnaire was prepared in an electronic version, and the questions were formulated both in Russian (this language is widely known by people over 40) and in English (some of the young people speak this language). However, there were people who required the questions to be translated on an ongoing basis into the Kyrgyz language (then the help of university employees was used).

Using the information from the organisers, 5 detailed questions (Q1-Q5) were prepared and included in the survey (Table 1). The number of questions was limited due to the fact that it was a pilot study, that the authors were on the premises of the University as invited guests and it was not appropriate to abuse the hosts' hospitality, as well as in order not to discourage the participants of the study.

In the quantitative part of the research carried out, a 5-point Likert scale was used (where 1. stood for completely disagree, and 5. for completely agree).

The quantitative results were developed on the basis of:
- comparisons of raw results obtained in groups of respondents belonging to Generation Z and those outside this group,
- calculating the mean values of the Likert scores and standard deviations for the entire surveyed population and for Generation Z and outside Generation Z respondents.

Moreover, due to the small size of the research sample, the percentage shares of the respondents' answers in relation to all answers, because the results obtained in this way would require significant rounding to make sure that the calculated values pertained to full persons rather than parts of them.

Qualitative research was carried out when filling in the questionnaires. They consisted in

Table 1. Questions Q1-Q5 with possible answers

No.	The content of the question	Value	Possible answers
Q1	Have you noticed any objects that do not fit into the Islamic culture?	1	There were no such objects
		2	Probably there were no such objects
		3	There was such an object
		4	Yes, there was 1 such object
		5	Yes, there were 2 such objects
Q2	Was the quality of the objects viewed in VR satisfactory?	1	Definitely not
		2	rather not
		3	I did not pay attention to it
		4	Some of it looked good, some was objectionable
		5	Absolutely yes
Q3	Was the quality of the VR application environment satisfactory?	1	Definitely not
		2	Rather not
		3	I did not pay attention to it
		4	Rather yes
		5	Totally yes
Q4	Have you managed to interact with the objects?	1	No (with none)
		2	With 1 object
		3	With 2–3 objects
		4	Almost always
		5	Yes (with all)
Q5*	Did you know and have contact with VR technology before?	1	I did not know this technology
		2	I heard about it
		3	I was generally interested in this technology
		4	I read about this technology and saw a simulation of people's behaviour
		5	I knew and have used it.

* Question Q5 was not directly related to activity in the VR environment.

collecting additional information on topics that were not defined in the questions asked.

Information on the purpose of the research, the manner of its implementation and technical issues were provided to the respondents during the seminar in which they participated. The tests were carried out using 3 mobile VR sets. The VR session consisted of:
- the respondent's movement in the virtual world of hujra,
- observing objects in the room,
- attempting to interact with objects.

The duration of a single VR session was approximately 90 seconds. Due to the pilot nature of the research, the obtained results were not distinguished according to the gender of the respondents, but a division was made into groups belonging or not belonging to the Z Generation.

After the VR session, participants filled in an electronic questionnaire and submitted their own comments

RESULTS

Results of quantitative research

The survey results obtained after the respondents' answers to the research questions posed are presented in Table 2.

The results obtained for research questions Q1-Q5 are shown in Figures 3–7. In addition to the data from table there are average and standard deviation for each group calculated.

The results obtained for question Q1 (Table 2) may indicate that the respondents did not feel at ease in the VR environment, they were focused primarily on the sensory experience (immersion) of being in a different reality. Only half of all respondents admitted with certainty that they had noticed such objects (1 or 2). The obtained results indicate a much lower perceptiveness in the group of respondents from outside the Generation Z (only 2 people noticed such objects), Figure 3. The average Likert value for the GZ group is over 1.5 times higher than for the OGZ group (with a much smaller SD), which proves that many people from the GZ group noticed objects that did not belong to Islamic culture.

In response to question Q2, it can be stated that only 6 people had reservations about the quality of the objects displayed – their geometric-realistic quality. The vast majority (20 people) had no objections. The obtained results indicate no difference between the two groups of respondents, taking into account their number, Fig. 4. It is easy to see that average results for each group were similar.

A similar tendency as in question Q2 was visible in the answer to question Q3 (the difference occurred in the sum components, Tab. 2). There was no difference between the two groups of respondents taking into account their number (Fig. 5). On the basis of these results, it becomes legitimate to say that the perception of the quality of the VR environment did not depend on the age of the respondents.

The results for question Q4 show a significant difference in the answers given between people belonging to different generations. People from Generation Z definitely had fewer problems with interacting in VR (12 people out of 17 participants) (Table 2, Fig. 6). GZ group shown better object interaction skills than OGZ group – the average value of the Likert Scale was almost twice as high. Only 2 people from outside the Generation Z coped with this problem.

The answers to the question Q5 showed that VR technology was new for the vast majority

Table 2. Summary of answers to questions Q1-Q5

Likert Scale	Q1			Q2			Q3			Q4			Q5		
	All	GZ	OGZ	All	GZ	OGZ	All	GZ	OGZ	All	GZ	OGZ	All	GZ	OGZ
1	5	1	4	1	1	0	2	1	1	6	2	5	7	1	6
2	1	0	1	5	3	2	4	3	1	5	3	2	4	2	2
3	7	5	2	12	8	4	12	7	5	6	5	1	9	8	1
4	5	4	1	6	4	2	3	2	1	4	3	1	4	4	0
5	8	7	1	2	1	1	5	4	1	4	4	0	2	2	0

All – all respondents.
GZ – respondents from Generation Z.
OGZ – respondents from outside of Generation Z.

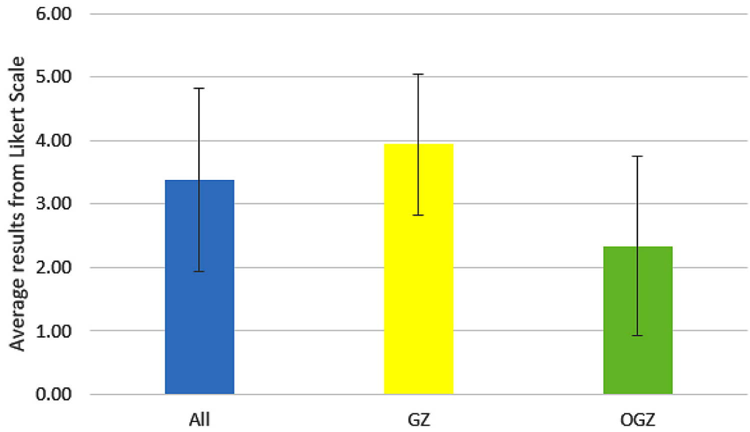

Fig. 3. Average and standard deviation (SD) of the answer to question Q1

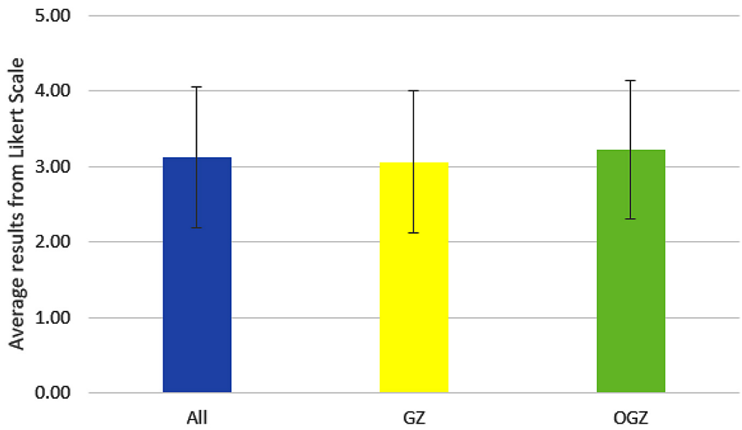

Fig. 4. Average and standard deviation of the answer to question Q2

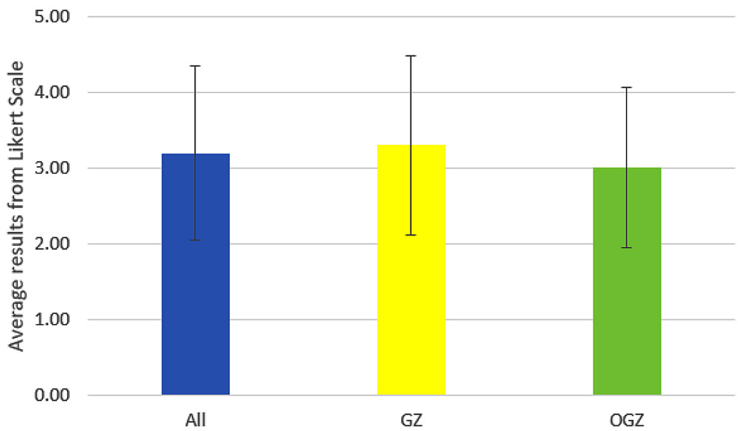

Fig. 5. Average and standard deviation of the answer to question Q3

of all participants (20 people out of 26) – Table 2, which confirmed earlier information obtained from the organisers of the seminar (Fig. 7). The low SD value of the OGZ group results from the fact that the vast majority had no contact with VR technology and gave the value 1.

Results of qualitative research

The topics raised by the respondents concerned:

- the possibility of enriching/replacing traditional museum exhibitions with solutions using VR technology,

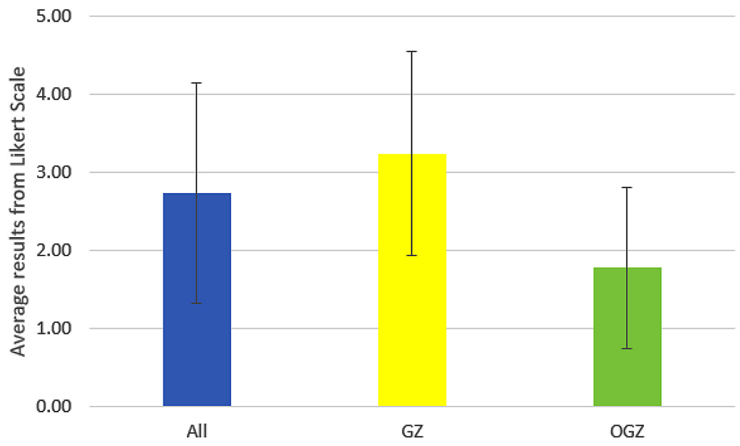

Fig. 6. Average and standard deviation of the answer to question Q4

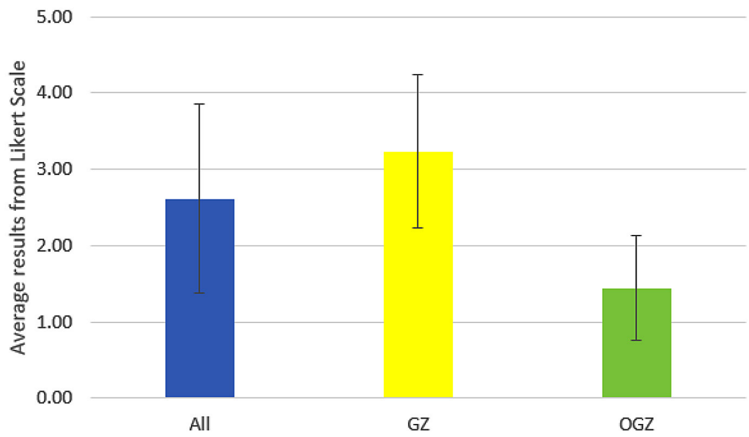

Fig. 7. Average and standard deviation of the answer to question Q5

- the possibility of creating VR worlds that would aggregate many cultures (certainly the inspiration for these statements was the fact of inserting objects from outside Islamic culture into the students' room),
- quality of models presented in VR environment,
- the possibility of enriching VR environment with additional 3D objects,
- the possibility of extending the VR session,
- the possibility of introducing information in the native language.

The last one indicates that the respondents were not entirely satisfied with the way the objects descriptions were displayed. Furthermore, the participants of the research said they were under a great impression that they could be so realistically in a room that they had never seen before and they had great joy from this possibility.

CONCLUSIONS

The results of the pilot tests involving users from different groups are very interesting:

- The quality of the presented models (question Q2) and the virtual stage (question Q3) was assessed mostly neutrally "I did not pay attention to it" – a Likert Scale value above 3 for all analyzed groups. According to the authors, this means that the developed environment for an interactive VR presentation turned out to be the so-called "Transparent", not causing conflicts while in it and not distracting respondents' comments, in the context of the content being transferred through the "Hujra" application. It should be added, however, that in the case of the OGZ group, the results for Q3 may be related to the results from Q5. Not paying attention to the quality of the application may also result from the lack of direct contact with VR devices, ignorance of technology and the virtual environment.

- A larger group of Generation Z representatives was able to adapt to an unusual way of interacting in the VR environment (question Q4) and to interact with at least 2–3 objects, unlike the other participants in the experiment (the OGZ group), who were not able to do this – the Likert Scale value below 1.8, Fig. 6.
- The respondents of the conducted research agreed that the use of VR technology in the broadly understood term of cultural heritage, conceived both as creating digital exhibitions, but also as a modern tool for researching knowledge about different cultures and recognising them by representative artefacts, is a very promising idea.

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