Comparing the impact of low-cost 360° cultural heritage videos displayed in 2D screens versus virtual reality headsets

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Abstract. The continuous price reduction of head mounted displays (HMDs) raises the following question in the field of cultural heritage: Is it possible to adapt desktop passive virtual reality (VR) 360° experiences for HMDs? This work presents a comparison of low-cost 360° videos of cultural heritage displayed across two devices: a desktop display and an HMD. The study case is the virtual reconstruction of Burgos (Spain) in 1921. The key factors of these videos are short duration, virtual reconstruction based on 3D modelling and photo editing and the inclusion of real actors performing out looping micro stories. The comparison of both displays devices has been carried out by a group of 32 students from the University of Burgos. The validation includes user satisfaction, knowledge acquisition and visual identification. The results are the following: 1) better knowledge acquisition and immersion in the HMD group, 2) better user satisfaction for the desktop group and 3) more fault identification related to the characters for the HMD group. Looking at these results, the most important elements to improve are the integration of characters and increase the length of the videos.

Keywords: Virtual Reality, Cultural heritage, Virtual reconstruction, 360°, Low cost

1 Introduction

Much of the cultural heritage has been lost over time. For this reason, the virtual reconstruction of heritage is a necessary tool for transmitting this knowledge, because it allows the transmission of historical knowledge in a very direct and visual way [1]. Virtual reconstruction also brings other advantages to the dissemination of cultural heritage, such as being able to access virtually to places with accessibility problems or restricted access [2].

adfa, p. 1, 2011.

Consequently, as technology advances, it is more common to carry out virtual reconstructions of heritage. Within this discipline, the creation of virtual reconstructions of heritage through virtual reality (VR) applications, whether interactive or passive, have a special importance. This is due to VR allows more immersion for users and the sense of "being there" [3].

Within VR applications we can differentiate between passive and interactive. Passive VR is the one that does not have very limited movement and interaction, otherwise in interactive experiences users can freely interact with the environment. In the VR experiences it is also possible to differentiate between those that are visualized on desktop displays and those that are visualized on head mounted displays (HMDs) [4]. Interactive virtual reconstructions of heritage are usually low-cost due to the low budget that is normally handled in this discipline [5]. Therefore, passive VR experiences find their place in cultural heritage [4].

The rise of low-cost HMDs like Oculus Quest is making these VR experiences widely used in education and cultural heritage [6], causing the transition from desktop passive VR applications to HMDs. This phenomenon raises the following question: Can a passive desktop VR experience be successfully displayed with HMDs with the same knowledge acquisition or user satisfaction?

Other researchers have already worked on porting and comparing desktop passive VR experiences to HMDs. Pietroni [7] in his virtual reconstruction of Villa Livia already adapted a passive VR desktop experience to HMDs. Work has also been done comparing different HMDs, such as Fabola [8] in the virtual reconstruction of the St. Andrews Cathedral or Petreli [9] in the reconstruction of the temple of Mars Ultor and the Dr Jenner's house. Also evaluating the impact of VR to other non-immersive digital methods, for example, the work of Checa [10], comparing a virtual reconstruction in video versus a passive VR HMD experience. But there is already a gap in VR research. Since it has not been investigated whether it is possible to effectively adapt a desktop passive VR experience for HMD.

This work presents the design and validation of the virtual reconstruction of 3 squares from the virtual reconstruction of Burgos in 1921 in 360° video, addressing this issue. This research compares: 1) usability and user satisfaction, 2) acquisition of knowledge, and 3) the visual relevance of the elements included in 360° videos displayed through two devices: a desktop screen and an HMD.

This paper is structured as follows. Section 2 explains the design of the experience, the virtual reconstruction of Burgos in the year 1921, from the choice of the reconstructions to their creation. In Section 3, the evaluation method is explained. Section 4 explains the results. Finally, the conclusions of this paper are in Section 5.

2 Study case: Burgos 1921

Burgos is a 1,200-year-old city in Spain. One of its most important monuments is the cathedral, a World Heritage Site. In 2021, Burgos Cathedral turned 800 years old. For these reasons, as part of the centennial celebrations of the cathedral in 2021, 3 virtual 360° reconstructions of the city were created. In these reconstructions 3 squares of the city can be seen as they looked like in 1921.

2.1 Design of the experience

The 360° video reconstructions want to represent the change in the urban space and the cultural change. In this century, the city has undergone great changes, such as remodelling of buildings, the pavement, the cathedral and even the total remodelling of the interior of its main square. In addition, the city has suffered technological and social changes such as the popularization of the automobile. For this reason, the experience was designed by reconstructing 3 important points of the city, by showing how different squares with different uses have changed. These squares are Santa María Square marked 1 in Figure 1, Main Square marked 2 and Llana de Afuera marked 3. All the squares. The 3 squares are located around the cathedral of the city.

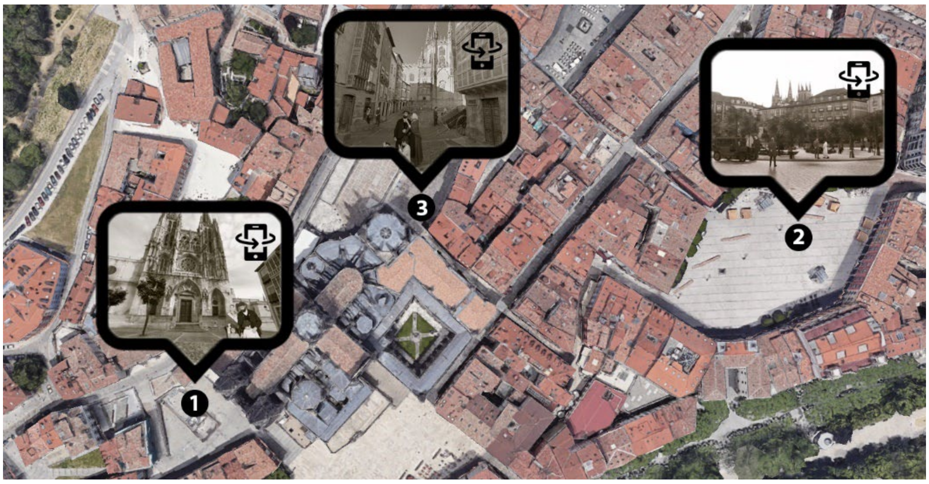

Fig. 1. The 3 squares and their location in Burgos

2.2 Design of the videos

To represent the changes in the urban space, the buildings have been digitally rebuilt and the squares have been reformed. The cultural change was represented with the inclusion of characters. Through the performance of looping micro-stories distributed throughout the virtual environment, the characters recounted situations of Burgos in 1921, such as waiting to take a photograph in front of the cathedral, as shown in Figure 2.

Fig. 2. People waiting to take a photo in the reconstruction of Santa Maria square

These 3 virtual reconstructions were designed to be visualized in situ and to compare reality with the reconstruction, by seeing them through a smartphone, or a cardboard. The procedure was proposed thinking of these visualization devices. For this same reason, the duration of each 360° video is short, around one and a half minutes. Figure 3a shows a final screenshot of the Santa María Square, Figure 3b of the Main Square and Figure 3c of Llana de Afuera.

Fig. 3a. Screenshot of the virtual reconstruction of Santa María Square

Fig. 3b. Screenshot of the virtual reconstruction of Main Square

Fig. 3a. Screenshot of the virtual reconstruction of Llana de Afuera

2.3 Reconstruction procedure

The main objective of this procedure was to recreate realistically the city of Burgos in 1921, by optimizing economic resources and with historical accuracy. For this, a procedure that combines several audiovisual techniques seeking a great level in realism with few economic resources was created.

The development process was as follows: 1) documentation, 2) assets creation and characters recording, and 3) digital composition of all the assets. The workflow and relationships between the different techniques are explained in Figure 4.

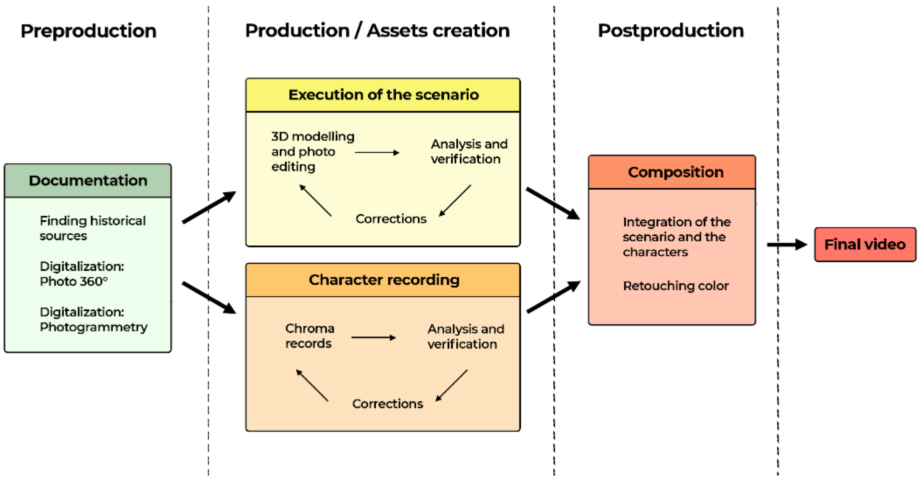

Fig. 4. Workflow used in virtual reconstruction

It is not the first time that this procedure has been used, by separating the creation of the scenario from the inclusion of the characters. Kwiatek [11] has already done something similar in his reconstruction of the Charles Chapel, including real characters on a 360° reconstruction. Also Rizvic [12] did something similar in her reconstruction of Villa Livia.

In the first step of the procedure, documentation, experts in historical analysis located all the necessary documentation, like blueprints and photos, to provide historical accuracy to the reconstruction. At the same time the 3 locations were digitized with 360° photos and photogrammetry. The 360° photos were later used as support for the virtual reconstruction. The parts of the city that had not undergone changes were kept from the 360° photo or slightly edited. Photogrammetry was used to have volume references in the 3D modelling step.

The production step was divided into two branches: the creation of environments and the recording of characters. Two different techniques were used to create the environments. Firstly, 3D modeling for those buildings or objects that had been lost over time. The modeling process used is explained in [13, 14]. This technique was used only in essential cases because it is the most expensive, but it is necessary when there were no remains to date. For the parts of the city that had not changed or changed little, the 360° photo of the squares was digitally edited. Over these images the 3D models were placed replacing remodeled buildings, the pavement or adding vehicles. The characters were recorded with chroma to include them after in the reconstruction. Attention to detail was paid during recording and the actors wore clothing of the 20s in Spain, as seen in Figure 5.

Fig. 5. Recording of the actors with chroma

This decision allowed lower costs and achieved a better historical accuracy with the characters. They were recorded with a common DLSR camera, and their perspective was later corrected in the next step. Also the light was previously calculated depending on where they will be placed. In both processes there was continous historical review.

In the last step of the procedure, the elements produced in the creation of assets were combined, rendering the 3D models on the 360° photos and combining the result with the images of the edited squares. Subsequently, the actors were introduced, correcting their perspective digitally to fit them in the reconstruction. The color of all the elements was retouched and matched to achieve the final composition, thus creating the 3 videos of Burgos in 1921.

The software used in the work were Blender for 3D modelling, Adobe Photoshop for photo editing and Adobe After Effects for video editing. The reasons to choose these programs were the low price and the experience of the team with the software.

The localized advantages and disadvantages in this procedure are the follows. It is a low-cost procedure but it achieves a high level of realism. Also, this method can get a high level of historical accuracy in the characters because they can be dressed and checked by experts while recording. This procedure is based on relying on photogrammetry and photo 360° to save modelling resources. For this reason, it can only be applied with heritage that has not been completely lost. 3 videos can be viewed at [15–17].

3 Evaluation

The evaluation was carried out with students of the degree in Media Communication and the Master in Communication and Multimedia Development of the University of Burgos. The group was formed by 32 students with a balanced gender distribution. They had an average age of 23 years, a minimum age of 20 and a maximum of 31. The students were divided equally into two groups, the one that visualized the 360° reconstructions through a high-end HMD (HCT Vive Pro Eye), hereinafter called the HMD group, and the one that did it through a desktop display, hereinafter called desktop group.

Both groups viewed the 360° videos in the following order: 1) Santa Maria Square, 2) Main Square, 3) Llana de Afuera. But the HMD group previously viewed another 1-minute 360° video to compensate for the increased acclimatization required by this device [4]. In this way, the duration of the experience for the desktop group was 4 and a half minutes and the duration of the HMD group was 5 and a half minutes. In Figure 6 some of the participants of the HMD group can be seen visualizing the experience.

Fig. 6. HMD group students visualizing the experience

After viewing the experience, both groups answered a questionnaire. The survey consisted in a set of questions divided into 4 blocks: usability, knowledge acquisition, visual elements and a suggestion section. To answer the questions, there were 3 possible response options. These responses options are the following: 1) Likert scale from 1 to 5, 2) open questions and 3) question with 2 or 3 options.

The usability block was meant to measure user satisfaction regarding duration and realism. It is also designed to know their estimation of movement and time, to check if there were differences between the two devices. The knowledge acquisition block was set to check which format transmits better historical information. For this, questions ask about the change in the use of the city, but also about the change in some specific elements, such as the cathedral. The visual element block was meant to check which elements have the greatest visual importance for users. Since the characters and the scene have been created separately in the reconstruction procedure, this block has also been divided into two groups. The first set of questions asks about the scenario, and the second about the characters. Finally, a fault identification question has been added to find out possible bugs in the reconstruction procedure. The last block asks users to indicate what things they would like to freely change. This block is intended to detect patterns not evaluated in the previous questions.

Likert scale questions have been used to find out the opinion of users in a standardized way. The scale if the Likert questions was 1 to 5. That is why they have been used in the usability block. The open questions had the objective of not biasing the users' response or not giving them clues about the correct answer. Choice questions were used when questions had very clear possible answers, such as yes or no. All questions can be seen in Table 1.

Table 1. List of questions

Code	***Type***	***Question***	***Posible Answers***
Q1	Usability	Lenght opinion	Likert scale
Q2	Usability	Realism opinion	Likert scale
Q3	Usability	Movement estimation	Likert scale
Q4	Usability	Lenght estimation	Open question
Q5	Knowledge acquisition	What was the use of the Llana de Afuera?	Open question
Q6	Knowledge acquisition	What changes has suffered the Main Square?	Open question

Q7	Knowledge acquisition	What changes has suffered the cathedral?	Open question
Q8	Knowledge acquisition	Have you seen changes in the pavement?	Open question
Q9	Knowledge acquisition	What was the most common vehicle?	Open question
Q10	Visual identification of 3D models	Have you seen the car moving?	Two options
Q11	Visual identification of 3D models	Which square do you think had more trees?	Three options
Q12	Visual identification of 3D models	Can you describe the most common curtains?	Open question
Q13	Visual identification of characters	Have you seen the common characters? Describe them.	Open question
Q14	Visual identification of characters	Have you seen childs? Describe them.	Open question
Q15	Visual identification of characters	Did you see what the photographer had underfoot? Describe them.	Open question
Q16	Visual identification of characters	Have you seen the characters they were reading? Describe them.	Open question
Q17	Visual identification of characters	Has any character caught your attention? Describe them.	Open question
Q18	Visual elements	Have you seen any error in the reconstruction? Describe them.	Open question
Q19	Suggestions	Do you have any suggestions to improve this experience?	Open question

4 Results

Regarding user satisfaction, there are similar results for both groups. In Q1, on the duration opinion, the HMD group achieved an average score of 2.8 against 3.0 for the desktop group. In this question the maximum score, 5 is considered too long and 1 too short. In Q2, on the opinion of realism, the HMD group achieved an average score of 4.12 against 4.18 of the desktop group. The scores of both groups are high and very similar. However, slightly better results can be observed for the desktop group. Doing a deeper analysis in user satisfaction, it can be seen how the HMD have 8 suggestions demanding more interaction compared to 3 of the desktop group. The desire for greater and better interaction which could explain this slightly lower result in the user satisfaction for the HMD group.

In the questions about space-time perception, greater differences can be seen. In Q3, about movement estimation, HMD group has estimated its movement as lower. This group has an average score of 3.7 compared to 4.3 for the desktop group. Regarding the estimation of the duration, Q4, the HMD group has obtained worse results. They have estimated the time at an average of 6.7 minutes, deviating more than a minute from real time (5.5m). In contrast, the desktop group has estimated the time at 4.5 minutes on average, being the correct answer in this case (4.5m). These two questions have in common a great difference in the dispersion of the answers. In both questions, the HMD group shows a greater dispersion of responses, especially in the movement estimation. This can be seen in Figure 7, in which the user score is represented on the y-axis and the two groups on the x-axis. This difference in results is probably because viewing through HMDs causes a greater sense of immersion.

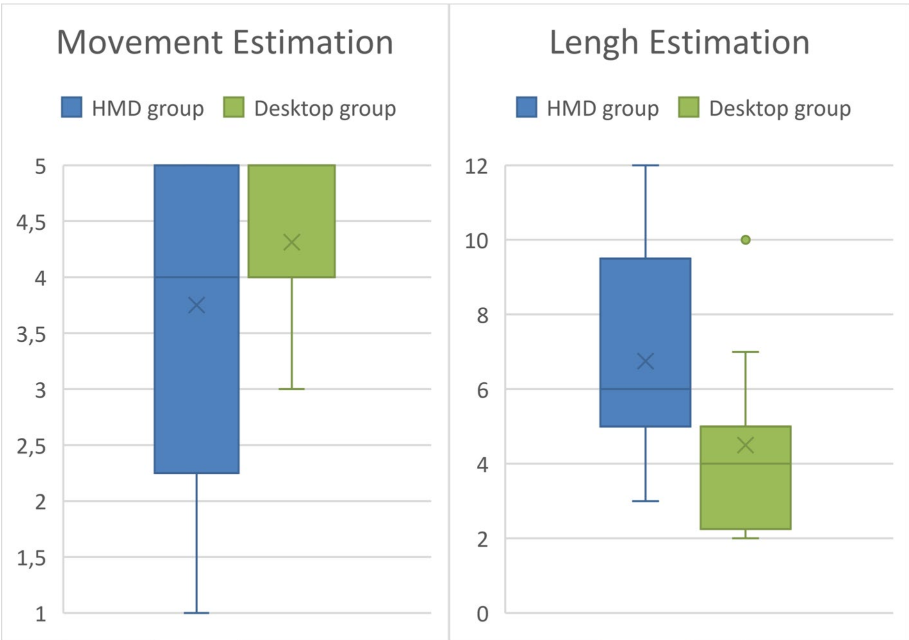

Fig. 7. Comparison of the dispersion of answers between the groups

The results in the knowledge acquisition questions block are as follows. To compare the results, scores have been normalized, given to the different answer points from 1 to 5. In this block a 1 means a completely wrong and 5 means the correct answer. The HMD group has achieved a better average score, 3.58 compared to 3.28 for the desktop group. But it has had worse scores in Q7, 1.68 vs. 2.06 for the desktop group, and in Q9 with 2.93 vs. 3.37 for the desktop group. These results are plotted in Figure 8. In this figure the average score of both groups is represented on the y-axis and each question and the total average score on the x-axis. This difference in results could be explained by a greater gaze dispersion for the HMD group. The questions in which this group has had the worst score, Q7 and Q9, are those that ask about specific elements, the cathedral and a car respectively. While those with the highest score asked about urban spaces as a whole, but not for a specific element. This result can be related to the previous section. As there is a greater immersion and dispersion for the HMD group, it is possible that certain elements have gone unnoticed for them.

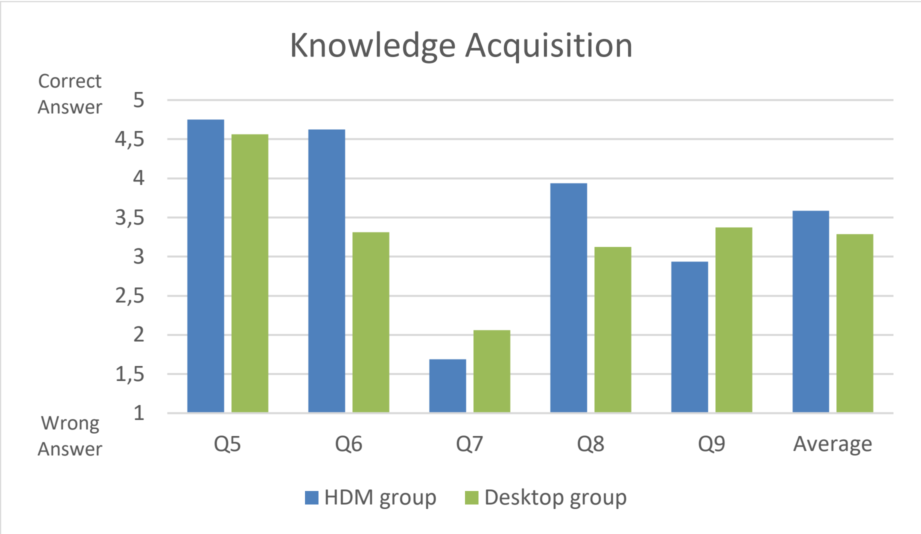

Fig. 8. Summary of answers in the block of knowledge acquisition

Regarding the visual element questions there are also significant differences. The score of this block has been counted giving one point for each correct identification of the users. Half of the block, questions Q10, Q11 and Q12, about the 3D elements of the reconstruction have obtained the same results for both groups. In the character identification questions, the HMD group has identified more characters except in one question, as it can be seen in Figure 9. The number of correct identifications of characters of each group in the questions is represented on the y-axis, and on the x-axis questions and groups.

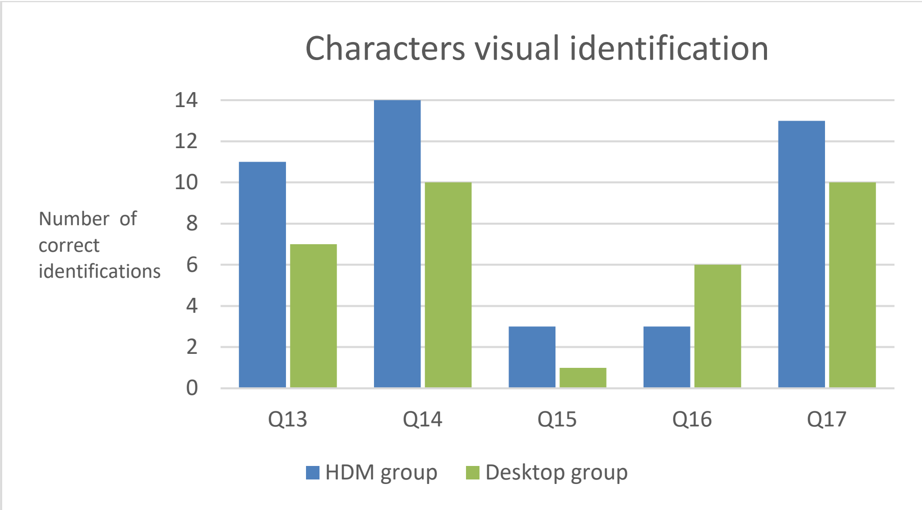

Fig. 9. Summary of answers in visual identification of the characters

In the same way, in Q18, about the identification of errors, only the HMD group identified errors on the characters, by notifying it 6 users, 37.5% of them. Those errors in the characters related to the scale. Those results are similar to those obtained in the research of Argyriou [18], which shows how characters are one of the most striking elements in a 360° video experience viewed through HMDs. This greater visual relevance of the characters has caused a greater transmission of knowledge about them, but also a greater identification of faults.

5 Conclusions

This paper presents the design and the comparison of a passive VR video 360° based experience of cultural heritage and designed for desktop across two display devices: a desktop display and an HMD. This research is useful to optimize the processes of creating passive VR experiences based on 360° video in cultural heritage, where the budget is usually low. The evaluation has been carried out by a group of 32 students from the University of Burgos. These students were divided into two groups of 16. One group visualized the experience through a desktop display, and the other with an HMD. Subsequently, they filled out a questionnaire from which the following results were extracted.

The HMD group presented a much greater dispersion of responses about space-time perception. They had better results in knowledge acquisition too. Finally, the characters had a greater visual relevance for this group. However, the desktop group showed better satisfaction, by having better results in their opinion about the realism and duration of the experience. Also, this group has identified fewer bugs than the HMD group.

Through the interpretation of these results, the following conclusions can be reached. Even though the HMD group has achieved better results in knowledge acquisition, the greater immersion provided by this device has caused worse results in some of these questions. Specifically, those who asked about specific elements of the videos. The greater visual relevance of the characters for the HMD group allows more knowledge to be transmitted through them. But it also makes them identify more flaws and ask for a better integration of the characters. This result may be related to the slightly lower realism score of the HMD group.

The comparison of these 3 videos has been satisfactory, but these results show elements that need to be improved in the procedure: 1) better integration of characters, to avoid reporting bugs related to them and 2) longer video duration to give users more time to focus on details when using an HMD.

Future works will focus on modifying this reconstruction procedure by considering these results to repeat the experiment. In this way, it is wanted to achieve a low-cost reconstruction process of 360° videos suitable for viewing through HMDs. The development of simple interactions will be also considered to increase users' satisfaction in VR experience as previous research has outlined [19, 20].

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