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REGULAR PAPER

A comparison study of AR applications versus pseudo-holographic systems as virtual exhibitors for luxury watch retail stores

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Abstract
The market of luxury watches has been continuously growing across the world, regardless of economic crisis. However, consumers can purchase online, on the web pages of the luxury watchmakers, the same product they can acquire in physical retail stores, producing a significant reduction in the overall sales of the latter ones. To reduce this trend, retail stores should increase their added-value services, one of which could be the use of virtual exhibitors in the shop. In this paper, we have developed two multimedia solutions (an Augmented Reality application and a pseudo-holographic system) for the creation of virtual exhibitors, and we have carried out a comparative study (based on real users) to measure which system would produce the best impact on users when used in traditional luxury watch retail stores. Our primary hypothesis was that there would be significant differences between the use of the mobile AR application and the use of the pseudo-holographic system. Our secondary hypothesis was that user preference for the mobile AR application would be higher than for the pseudo-holographic system.

Keywords AR applications · Pseudo-holographic systems · Performance evaluation

1 Introduction

The market of luxury goods and services has been continuously growing across the world, regardless of economic crisis or wealth distribution. In general terms, the overall luxury industry has experienced a considerable growth of a 4%, up to an estimated 1.08 trillion Euros in retail sales value in 2016 [13]. Although outstanding international brands such as Versace and Prada did not have corporate websites until 2005 and 2007, respectively, they finally conducted business on the Internet as a result of evolving consumer needs and expectations [28]. Just in the market of personal luxury goods, the billing from the online selling is expected to reach 74 billion Euros, corresponding to 20% of the total sales volume across the world [2, 15].

The luxury watch industry is in a unique position within this context. On the one hand, the market is completely polarized, with a reduced set of brands controlling the whole sales market. On the other hand, consumers can purchase online, on the web pages of the luxury watchmakers, the same product they used to purchase in traditional luxury watch retail stores, avoiding the travel to the physical store and sometimes enjoying significant discounts [23].

Luxury watches are singular products, due to different reasons. They intend to be unique, differentiated products, since customers demand exclusive products. For this reason, they typically allow a certain level of customization from the manufacturer, generating complete product lines with small variations in the accessories. Most of the models manufactured by the main luxury watchmakers typically may vary at least the bands, bezels and dials/spheres of their base model. Since the cost of each watch is very high (above 4000 dollars) retail stores usually have a single representative model from the range of luxury watches commercialized by watchmakers in their showcases. On the contrary, the

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web portals of the watchmakers allow the user to select and purchase from the complete catalogue of products and accessories of the watchmaker. This is one of the main factors that have produced an average sales reduction of up to 35% in traditional luxury watch stores [15]. To reduce this trend, retail stores should increase their added-value services. One of these services could consist in virtual exhibitors in the shop, which would allow customers to try on many watches with different configuration options without investing huge amounts of money in large physical exhibitors.

In this paper, we have developed two multimedia solutions for the creation of virtual exhibitors, and we have carried out a comparative study (based on real users) to measure the user impact. Both solutions are based on 3D real-time, interactive graphics technologies: a pseudo-holographic system based on a Cheoptics 360 projector [1], and an Augmented Reality (AR) application. Since the cost of both systems is similar, the purpose of this work is to test which system would produce the best impact on users when used as virtual exhibitors in traditional luxury watch retail stores. It is important to note that no funding from watchmakers was provided to support this research, although our motivation is to use this information to develop future commercial applications in this area. In particular, we have carried out a study where, using a real situation, we compare the effectiveness of a mobile AR application to the effectiveness of a Cheoptics-based pseudo-hologram for trying on and selecting a given model and configuration from a limited showcase of four watch manufacturers. In addition, we have evaluated the usability of the system and the user preferences with respect to these applications, using a population of thirty-nine final users. In this study, our primary hypothesis was that there would be significant differences between the use of the mobile AR application and the use of the pseudo-holographic system. Our secondary hypothesis was that the user satisfaction with the mobile AR application would be higher than the one achieved with the pseudo-holographic system, causing a preference for the AR system.

The rest of the paper is structured as follows. Section 2 shows the related work in the evaluation of AR systems and pseudo-holograms. Next, Sect. 3 describes the method of analysis used. Section 4 describes in detail both the AR application and the pseudo-holographic system developed for acting as a virtual exhibitors. Moreover, Sect. 5 explains all the aspects of the study carried out with real users. Section 6 presents and analyzes the comparative results of the experiment. Finally, Sect. 7 presents the main concluding remarks of the comparative study.

2 Related work

Cheoptics360 is a 3D visualization system developed by viZoo [1] which is based on a reflection pseudo-holographic stereogram. This pyramid-shaped display system allows 3D-objects to appear and be observed from a 360 degrees view. The pyramid display is made of half-mirror glasses on top of a LED monitor, generating virtual images which are transparently overlapped through the half-mirror glasses, producing a 3D illusion of both objects and scenery. Figure 1a shows an image of the design of our system, whereas Fig. 1b shows the final aspect of our development based on Cheoptics360. The pseudo-holographic virtual exhibitor developed in our labs is slightly bigger than the one presented in the original model [1]. In particular, our pseudo-holographic system allows object scenes of size up to 21.0 x 11.0 cm to be floating on air, and they can be observed by users from three of the four possible sides. We have carried out some interesting improvements in the interaction with the device. In particular, we have designed a simple smartphone application that interacts with the pseudo-holographic system and allows the user to select the watch base model from among some of the most representative models of different luxury watchmakers. It also allows the 3D visualization of different combinations of bands, bezels and spheres.

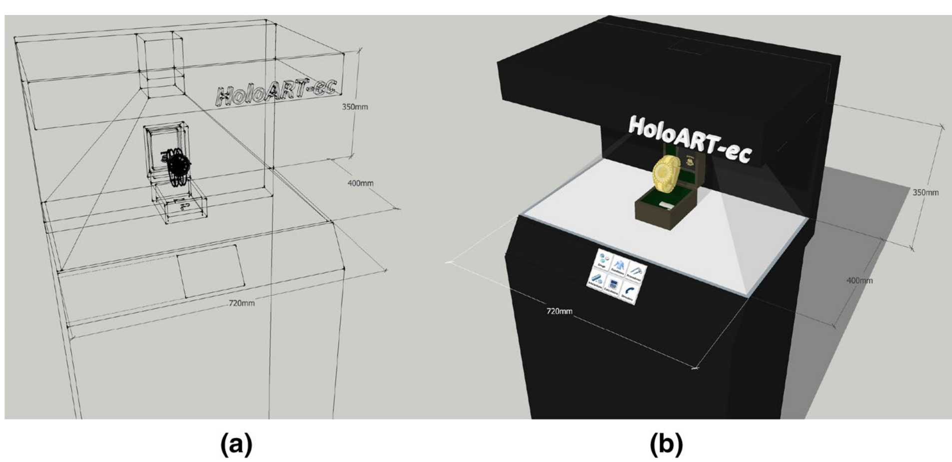

Fig. 1 Images of the system developed **a** delineated, **b** final design

Several works have addressed the problem of creating pseudo-holographic displays [30, 34]. The most accepted approach is probably the virtual showcase paradigm [7, 42], which has been used, for instance, for digital storytelling [9]. Although this technology has obvious applications for marketing purposes (known as "holopromotion") and it seems to have a big future ahead [16]), to the best of our knowledge there are no reports of this kind of studies in the academic community with this type of device.

On other hand, Augmented Reality (AR) has emerged as one of the rapidly developing technologies used in both physical and online trading to enhance the selling environment and shopping experience [11]. Nevertheless, from our perspective, most of the research efforts in AR have been focused on two different topics: tracking and visualization technology. Many contributions are focused on improving the real-time detection and tracking of AR systems [6, 40, 41], which has enabled a high-fidelity fusion of real world images with 3D computer-generated objects in real time. Another significant part of the work on this field has been focused on improving both the visualization devices, the technologies [24, 26] and the interaction devices involved in Augmented Reality [18, 33]. The occlusion problem has been also the subject of much research regarding visualization [36], since it is a key feature for providing a seamless integration of virtual and real objects.

Most of the works focused on evaluating user experience have been developed for evaluating prototypes in aspects related to perception [5], the performance improvement in the execution of different tasks [17] or usability [14]. This latter quality attribute has been evaluated in Augmented Reality for both the definition and utilization of different metrics [35] and the establishment of usability-oriented guidelines for the design of applications [38].

One of the first and most common applications of Augmented Reality technologies is retail, in which this paradigm can provide a pleasant and inviting shopping experience to the customers [44]. Many AR systems have been proposed in this context, especially the so-called virtual fitting rooms or virtual try-ons, where customers can virtually fit on their body different clothes and complements [31]. Other contributions have evaluated the user experience when using smartphone applications based on AR in the context of shopping centers [29]. Some works have analyzed the suitability of using an AR interface with respect to other technologies, for marketing and commercial purposes. For instance, in [19] the use of AR is compared with the use of maps and a list-based interface for searching and browsing location-based information. Another example is the work presented in [43], where consumer responses to three different ad formats are analyzed, including the use of AR-based ads. In [32], two AR-based treatments were examined and compared to traditional online shopping in the sunglass market. Results show that AR positively influences the retail user experience. Several similar works can be found in the academic literature and a good review can be found in [12], where the authors conclude that "consumers react positively to AR's entertaining and experiential value" and that "AR helps decrease the perceived cognitive risk arising from the uncertainty of not seeing products, and their combinations". Nevertheless, existing research suggest that more efficient and consumer-friendly applications should be designed for a successful adoption of AR in retail shopping.

Despite the various potential applications of these two technologies (pseudo-holography and Augmented Reality) in retail and marketing, to the best of our knowledge, no comparative studies evaluating user satisfaction/preference with these two technologies have been performed in the context of virtual exhibitors. In fact, no similar works analyzing the use and acceptation of pseudo-holographic devices in retail applications have been found. This is one of the main contributions of this paper.

3 Methods

The comparative analysis of the solution based on a mobile AR application and the solution based on a pseudo-holographic projector Cheoptics360 was carried out in the following way: first, each of the participants started his/her trial reading written instructions (in paper) explaining how to interpret the information yielded by the systems evaluated (the Cheoptics360 pseudo-holographic projector, denoted in the rest of the paper as the pseudo-hologram, and the AR app installed on the tablet used for the experiments). Next, the user watched a 4-min demonstrative video showing the same functionality than the written instructions, to improve the understanding of the working of the two systems. Before starting the experimentation tasks, a member of our staff checked that the user completely understood both systems, adding a final explanation if necessary. Then, the user filled out a consent form as well as a questionnaire with their personal and professional demographics. Two participants refused to sign the consent form, and another one did not cooperate during the experiment, and thus these three participants were excluded from the comparative study. At that point, the task users were prompted to complete (selecting the watch they liked the best from the pieces and accessories provided by each of the systems) was explained to the participants.

Both systems provided four unisex base watches coming from four classical, well-known brands in the world of watchmakers. The functionality, models and accessories were the same in both systems. Since one of the critical aspects in the shopping experience of this kind of products consists in providing different configurations of the final aspect of the watch, both systems allowed the selection of the most usual customizable elements: the dials, spheres and bands, providing three different options for each of these elements. Thus, both systems showed the users a range of 108 possible watch configurations, among which the user should select a single one, the one he/she liked the best. Figure 2a shows an actual screenshot of the mobile AR app interface at the moment when a user selects a base model and configures the desired watch. In the lower part of the screen, users have a series of buttons with which they can change (from left to right) the dials, spheres and bands of each of the watch models. Figure 2b shows the 27 possible watch configurations that both systems offer for each of the four base models. In the case of the AR application, it would be also possible to use it at home for online shopping, although the experience should be more appealing in the physical retail store because the setup (AR markers, light conditions, camera parameters, tablet) would be optimized for this particular scenario.

Since the selection and purchase processes should be accomplished in a limited time, the participants were instructed to avoid stopping or getting held up with any circumstance unrelated to the experiment, such as commenting the test with other participants, or using the tablet in the experiment for other purposes. The staff checked that all the participants had switched off their personal mobile phones, to avoid potential noise in the measurements. No incidences were reported in this sense. Finally, the participants were told that although both systems showed the same catalogue of watches and possible configurations, it was possible that they could select a different watch configuration (even a different model), since the interactive 3D models displayed in the AR app and the pseudo-hologram may differ in terms of illumination and 3D depth perception. Once the participants were trained to use both systems to select their final configuration, they were provided with a tablet to execute the AR app, and a smartphone as the mobile device to interact with the 3D elements displayed in the pseudo-holographic system. Both devices included a single icon in their desktop, corresponding to the system evaluated in the experiment. As a result, no staff intervention for helping the participants was required during the tests. Figure 3a shows a snapshot of a trial where the participant is evaluating the pseudo-hologram, and Fig. 3b shows a snapshot of the trial where the same participant is evaluating the AR app. In both cases, the participant is visualizing the same watch configuration. The interface used for the smartphone application employed in the pseudo-holographic system is the same as in the AR application (Fig. 2) and it can be seen in Fig. 3a. The only difference is that the final aspect of the watch is not shown in the smartphone but in the pseudo-holographic display.

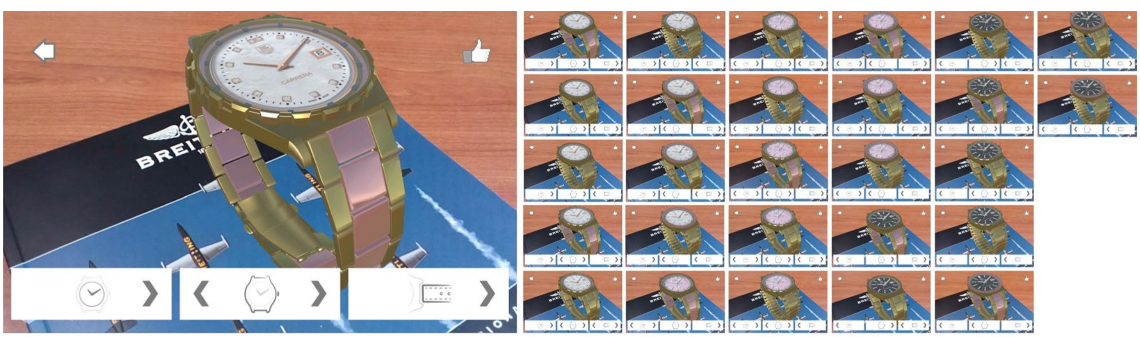
(a) (b)

Fig. 2 Images of the AR App interface

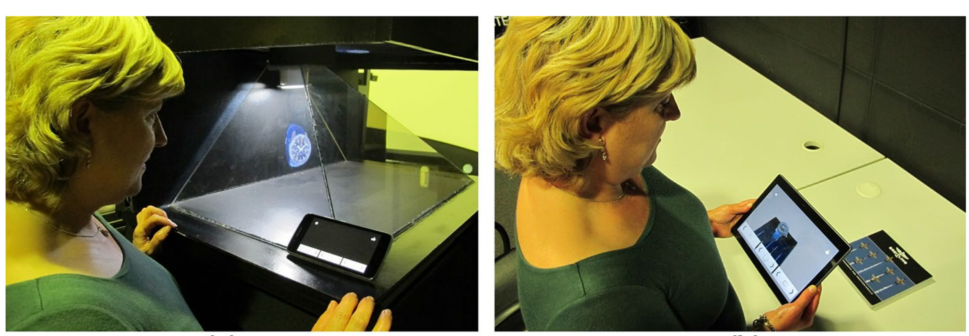
(a) (b)

Fig. 3 Snapshot of a real experiment where the same participant is evaluating **a** the pseudo-hologram and **b** the AR App

Once the participants decided which watch configuration they preferred, they should click on an fist-up icon located on the top part of the desktop. This action played a sound, and it caused the system to display in the screen the total time elapsed from the beginning of the trial. The acoustic signal allowed the staff present in the room to check the correct utilization of the system. After completing each one of the alternatives included in the experiment (mobile AR app or pseudo-holographic system), the participants filled out a written questionnaire regarding their experience, and at that point, the staff wrote down in the questionnaire the time required by the participant to complete the trial.

Since the four watch models employed for the experiment are well-known by the general public, we invited professors, students and university staff from the science campus of the University of Valencia (Spain) to become test participants. The trial sessions were organized through "Eventbrite" [4], a self-service event management and promotion website.

4 Exposition

In this section, we describe the methods for producing the illusion of having a 3D virtual object placed in a real location. The first method is based on the use of hand-held video-based Augmented Reality, using as tracking method a predefined set of fiducial markers detected in a reference image, on top of which the augmented object is rendered. The second method is based on the optic illusion known as "Pepper's Ghost" effect [8], which uses optic properties of semi-reflective surfaces (half mirrors) to generate the effect of having an object projected in the air. We briefly explain each method from the point of view of camera configurations and registration between real and synthetic elements in the test scenario. The 3D application engine in both cases has been Unity [22]. Unity 5.6 multiplatform engine was used to generate the Android app which is running the AR test. The same environment was used to create a 64-bit Windows application to support the pseudo-holographic system based on a Cheoptics pyramid. The advantage of using the Unity development environment is that it is possible to re-use most of the 3D modeling and animation elements for both experiments. The 3D content of these two applications was created by a 3D designer, who created these virtual reproductions from public repositories of textures and 3D models, using 3D modeling software to customize them.

Regarding the hardware platforms, the tablet executing the mobile AR app was a Samsung Galaxy Tab A 10.1, which includes a Samsung Exynos 7870 processor (1.6 GHz octa-core), 2 GB RAM, a 10.1" WUXGA (1920 x 1200 pixels) display, 8 MP primary camera, and a 2.0 MP front camera executing Android 6.0 (Marshmallow). The pseudo-hologram application was executed on an HP ENVY 750-220 Desktop, including an Intel Core i5 6400 3.20 GHz processor, 8 GB RAM, 1 TB HDD, NVIDIA GeForce GTX 970 graphic card, and a Samsung UE19ES4000 Monitor (19.0, 1280 x 1024 pixels). The operating system installed in this platform was Windows 10 Pro 64 bits. Finally, the smartphone executing the mobile app interacting with the pseudo-hologram system was a Motorola G5, including a Qualcomm Snapdragon 430 processor (1.4 GHz octa-core), 3 GB RAM, a 5.0" IPS LCD Full HD (1080 x 1920 pixels) display, 13 MP primary camera and a 5 MP front camera executing Android 7.0 (Nougat). The mobile AR application achieved a frame rate of 30 FPS and a tracking accuracy of 3-5 mm, while the pseudo-holographic system yielded a frame rate of 50 FPS.

4.1 Camera and tracking configuration of the mobile Augmented Reality app

In this method, the camera of the mobile device (tablet) is used to capture the real world, and an image of the 3D synthetic object is superimposed on top of this real-time video feed when it is displayed on the device screen. To have a proper illusion of having a 3D extra object in the actual environment, several conditions must be fulfilled:

- The virtual camera intrinsic parameters (focal lens, etc.) used to render the 3D synthetic object should be coherent with the video camera that is being used to capture the actual environment, to get the illusion of a correct size of the 3D augmented object compared to the real world objects.
- The virtual camera extrinsic parameters (camera position, orientation) should be correctly computed in real time, to keep the proper registration between the 3D augmented object and the surrounding actual environment. This requires using a common reference system for both the actual camera and the virtual camera that is being moved by the user around the augmented object with the purpose of appreciating different details. This condition is commonly known as tracking in AR literature [6, 14, 40].

Figure 4 shows an example of the different coordinate systems involved in an AR video-based architecture like the one used in the experiments presented. Different techniques should be combined to achieve a practical implementation of the tracking system. Nevertheless, there are several well-known libraries which provide these functionalities. Moreover, these libraries are optimized for the hardware present in typical mobile phones. For the purpose of the experiment, we have used Vuforia, a commercial library [27]. The main advantage of this library for our case is that it can be also integrated in the Unity 3D development platform, which

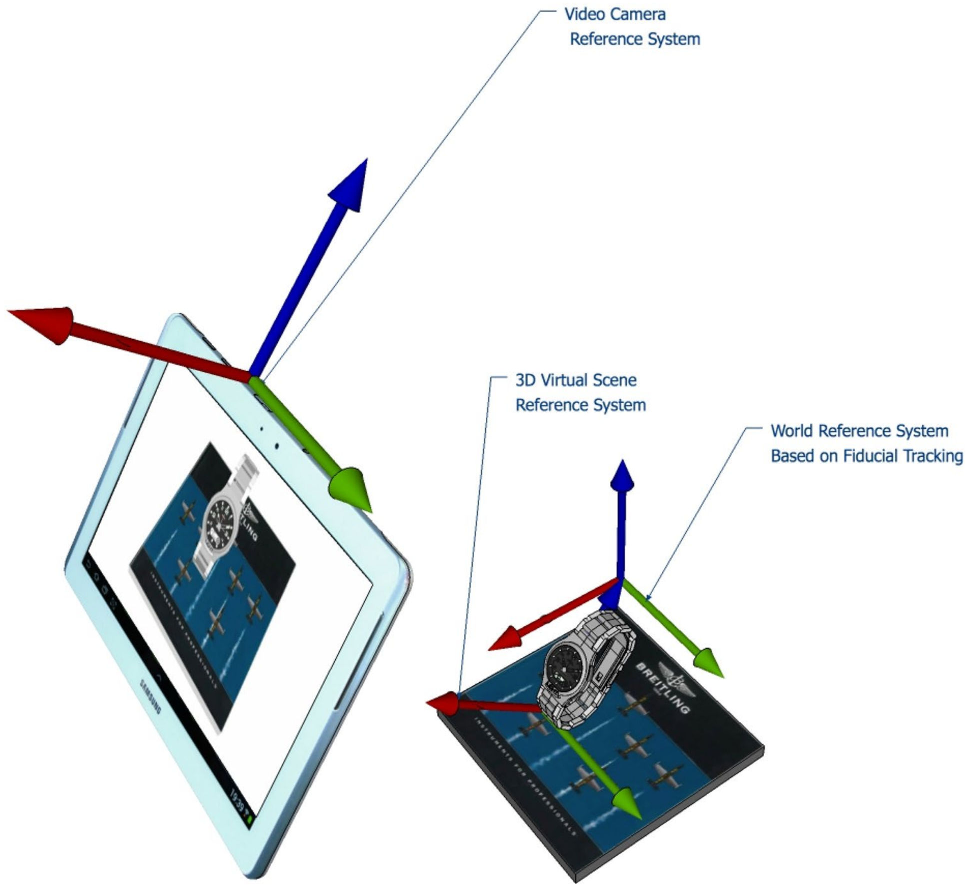

Fig. 4 Coordinate systems in AR tracking

makes quite straight forward the generation of the mobile app used in the final experiments.

The Vuforia library offers several tracking methods. The one that has been used for the experiment is based on the use of fiducial elements in a reference tracking image. Figure 5 shows an example of a base tracking image and the fiducial elements that Vuforia uses to keep the 3D tracking of the actual camera relative to this image.

4.2 Cheoptic pyramid image generation

The pseudo-holographic system based on a Cheoptic pyramid to display the augmented object also uses Unity as the 3D rendering engine. A 64-bit Windows application connected to a 19-inch LED display is used to produce the final 3D illusion. In this case, we only need static cameras

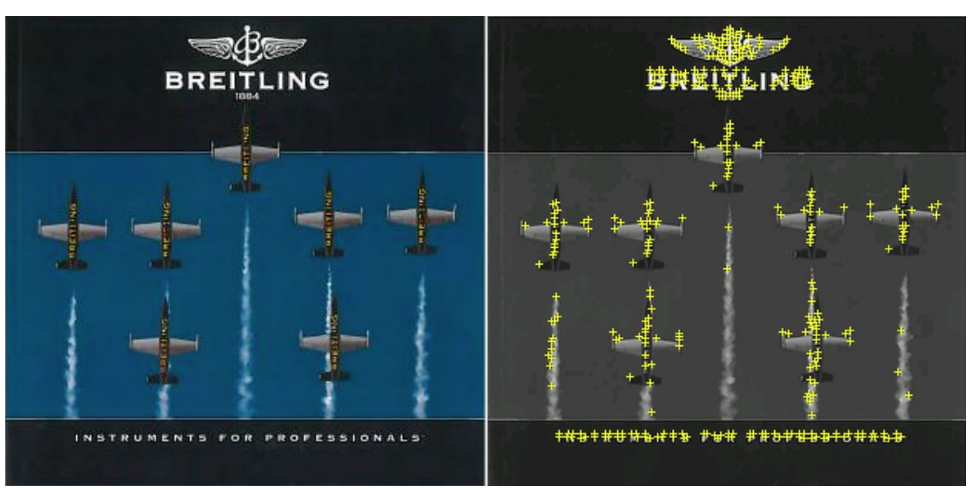

Fig. 5 Base tracking image and the fiducial elements within that image

which must be configured coherently with the physical construction of the Cheoptic display.

Figure 6 shows a schematic view of the optical principle that supports the "Pepper's Ghost" effect. In this effect, some of the incidental rays from a lighted stage are refracted through a glass towards the users, while some other incidental rays from the hidden 3D scene are reflected by the glass. The depth distance *L* (5 cm.) in the user's view ray from the half mirror glass to the location of the optical illusion equals the vertical distance from the half mirror glass to the actual object (or its LED display image). Therefore, one 3D image of the synthetic object is needed for each half mirror used to create the illusion.

Our experiment used a 270 degree 3-sided pyramid, and therefore three half mirrors are needed. Figure 7 shows a schematic description of the physical system used. This figure shows how three half-mirror elements are used: one for the front view of the object and two for the lateral right and left views (lateral mirrors with a size of half of the pyramid base). Although there are three different images, the

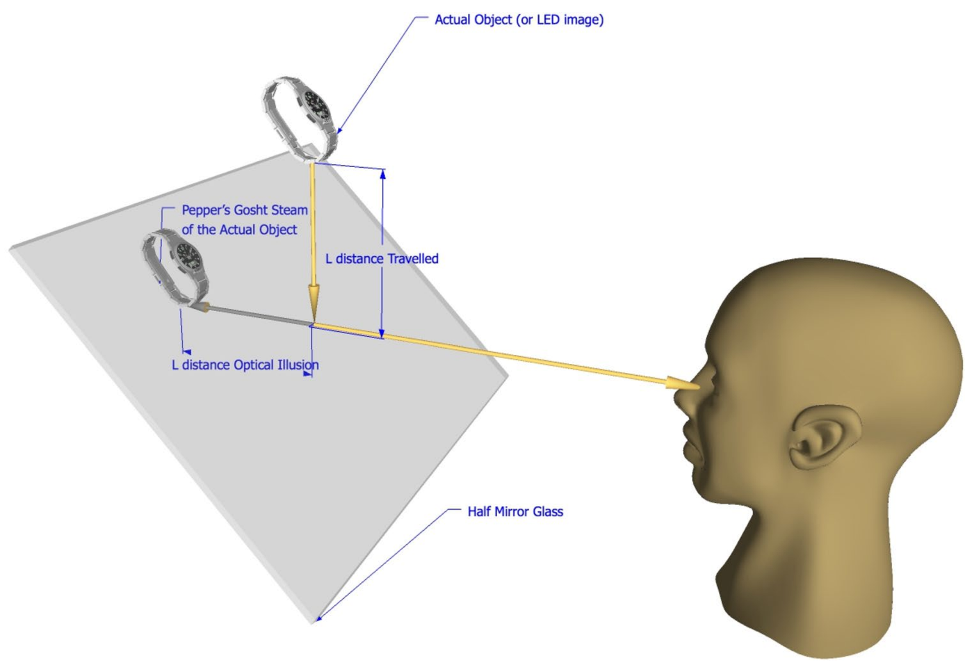

Fig. 6 Schematic view of the optical principle behind the "Pepper's Ghost" effect

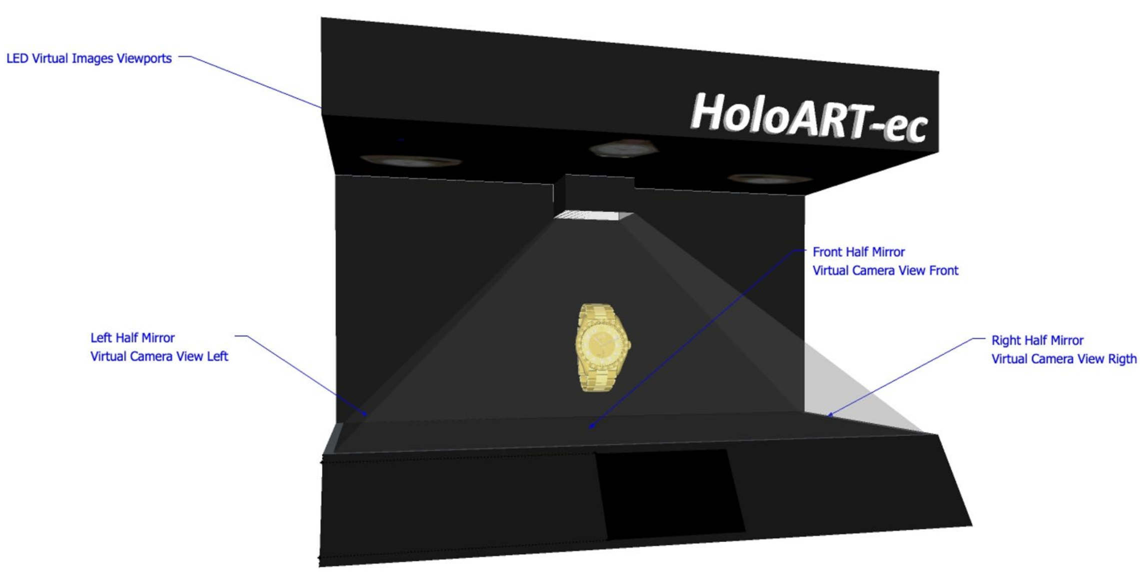

Fig. 7 An example of the 270-degrees half pyramid used in the experiment

application only uses one visual LED display, in which three different viewports with the proper orientation are rendered (landscape for front view, and portrait for lateral views).

One of the main problems in this experiment is to decide the extrinsic and intrinsic parameters of the virtual cameras to produce these three images. These parameters will depend on the relative position of the observer with respect to the pyramid center. However, no tracking system for the user head has been used, since it would hinder the existence of simultaneous observers, a common situation in this kind of retail stores. Instead, a general assumption should be made, assuming that the user will observe the pseudo-holographic image near the “privileged point”, which is the point from where the image is correctly observed (this is the point in which the reflection of the image travels the same distance as the refraction). As a result, if the observer is in this privileged location, then the perception will be perfect, but when the user moves around the pseudo-holographic system then perception will become slightly distorted. Nevertheless, this effect often remained undetected by users, who were more attracted by the illusion and did not pay attention to these small errors. Similar effects occur in 3D cinemas, where the stereoscopic pair is only correct for one or few observers in the room, but the rest of viewers still enjoy the VR experience. In the case of this pseudo-holographic device, as it does not use binocular vision, the distortion is harder to detect.

It is important to point out that some manual software adjustments had to be done, to keep continuity on the edges of the pyramid when the users move around the object to see lateral views. For this reason, the generated application allows performing small adjustments to get the maximum visual continuity on the edges between front and lateral images.

5 Study

The first objective of the study is to analyze if there are differences in the use of these two systems. The second objective is to analyze which system results more attractive for the luxury watch retail market. In this second objective, we also analyze which system would be recommended by the users for the installation in a retail store, a question that is slightly different from asking only which system is more attractive.

5.1 Participants

We have carried out a study involving thirty-nine valid participants to obtain statistically significant results [20]. Initially, we started the experiment with 42 people. However, two of them did not sign the explicit consent form about data gathering, and they were asked to leave the room before the start of the experiment. From the rest of the 40 people, one of them did not cooperate with the staff. He did not correctly perform the actions indicated by the staff, and he did not fill out any of the questionnaires. From these 39 people correctly validated, twelve of them were women (30.77%) and twenty-seven men (69.23%). The participants’ age ranged between twenty and fifty-four. The average age and standard deviation was 27.15 ± 8.49. We split the participants into two groups of nineteen and twenty people (denoted as groups A and B), randomly assigning the participants to each group. Each group was composed of six women and thirteen/fourteen men. From the thirty-nine people participating in the study, ten people (25.64%) had not any a priori computer skills (they had not any degree nor occupation related to computers). The remaining twenty-nine people (74.36%) were either professionals working on computer-related fields (fourteen people, 35.90%) or they were studying the Computer Engineering or a similar degree (fifteen people, 38.43%).

5.2 Measurements

Different metrics were obtained during and after the watch selection process. The measurements came from the participants and from the staff (observers) through two questionnaires that they should fill out at different moments, as described below. In particular, we used the questionnaires shown in Tables 1 and 2. The first questionnaire was composed of seven 7-scale Likert questions, plus a 3D perception question which used a 7-scale discrete ordered rating instead of a Likert scale. The second questionnaire was an

Table 1 First questionnaire, showing the eight 7-scale questions of the experiment

$Q1$	Did you have fun playing? (fun experience)
$Q2$	I never found it uncomfortable to use the system (ergonomy)
$Q3$	I did not perceive delays between my actions and their results (interaction)
$Q4$	It would have been great to have more watches for visualization (satisfaction)
$Q5$	I would like to test the system with different objects (suitability)
$Q6$	I find the application easy to use (difficulty)
$Q7$	The system provides a faithful idea of the watch’s final aspect (usefulness)
3D	Mark the depth perception yielded by the system

Table 2 Additional questions in the second questionnaire

Which system do you like the most?
Which system would you recommend as a virtual exhibitor?

extension of the first one, since it included the same questions shown in the first questionnaire plus the ones shown in Table 2, which are related to our secondary hypothesis. In all Likert questions, 1 means "strongly disagree" and 7 means "strongly agree". In the eighth question, 1 represents the poorest possible 3D perception, whereas 7 represents the most believable one.

5.3 Procedure

As described above, the participants in the study are split into two groups, denoted as A and B. The reason behind this separation is to check if the order in which the tests with the two systems are performed has an effect on the perception of the system and the final selection made. The procedure followed by the participants is illustrated in Fig. 8. Group A participants carried out the watch selection process first using the mobile AR application, and then they filled out the first questionnaire. After that, they repeated the selection process using the pseudo-holographic system and filled out the second questionnaire. Group B participants followed the same procedure, but exchanging the systems used for selecting the watch. In both groups, the time required to complete the process (excluding the time needed to answer the questionnaire) when using either of these systems was accounted.

6 Results and discussion

In this section, we analyze the data obtained about the usability of the systems and user preferences with respect to the mobile AR app and the pseudo-holographic device. All data have been collected using questionnaires. We have used the IBM SPSS statistics 24 program. For all of the results shown below, all significance tests were two-tailed and conducted at the 0.05 significance level.

First, we analyzed if the collected data follow a normal distribution. For instance, the dataset corresponding to the 3D perception of users was tested using the Kolmogorov–Smirnov test [25] ($D = 0.1782$ and p value = 0.3251), the Anderson–Darling test [3] ($A = 0.4108$ and p value = 0.1501), and the Shapiro–Wilk test [37] ($W = 0.6950$ and p value = 0.2864). These results confirmed that the dataset follows a normal distribution. We followed the same procedure with the other datasets and found them to have all a normal distribution. Therefore, we used the following parametric tests: the t test and the Cohen's test for paired and unpaired data, as well as multifactorial ANOVA for analyzing relationships among different parameters involved in the experiment.

Table 3 shows the study of statistically significant differences between the results of AR and the pseudo-hologram comparing the results for the first questionnaire for both groups (the questions asked are shown in Table 1). In particular, it shows the average values and standard deviations for independent groups that played the AR or the pseudo-hologram test first, and t tests assuming equal variances. In addition, this table shows the average user opinion about the 3D effects of each system (row labeled with "3D" in the left-most column), the average overall score assigned to each system (row labeled as "Sc."), and the average time (in seconds) required by the users to complete the test (row labeled as "Time"). Although it is not shown in the table,

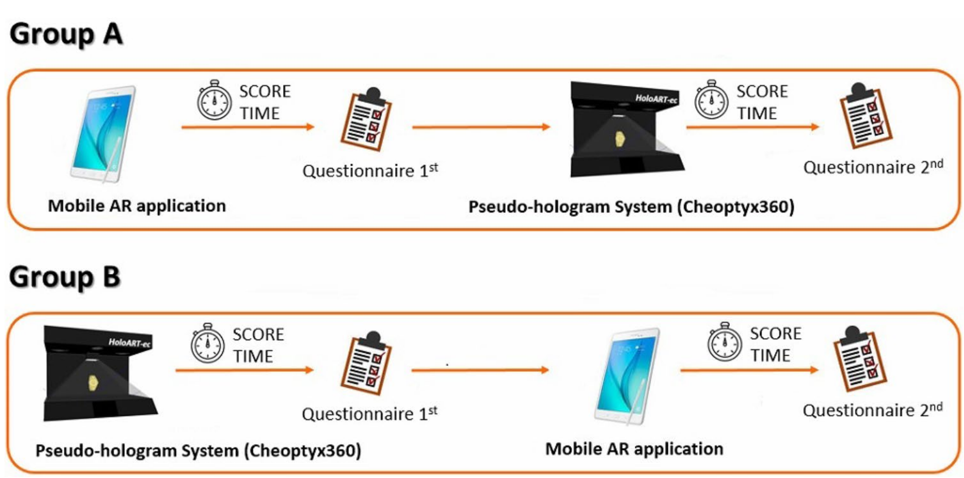

Fig. 8 Schematic view of the process followed by each group of participants

Table 3 Study of statistically significant differences between the results of AR and pseudo-hologram questionnaires

	AR		Pseudo-hologram				
	Avg.	SD	Avg.	SD.	*T* student	*p*	Cohen's *d*
*Q*1	6.650	0.587	6.150	0.933	0.0496	0.050	0.658
*Q*2	5.200	1.989	5.850	1.565	0.2580	0.258	− 0.366
*Q*3	6.450	0.605	6.100	1.586	0.3623	0.366	0.319
*Q*4	6.350	0.933	6.300	1.218	0.8849	0.885	0.046
*Q*5	6.600	0.598	5.950	1.146	0.0304	0.320	0.745
*Q*6	6.650	0.587	6.500	1.000	0.5664	0.566	0.189
*Q*7	6.100	0.852	6.100	0.968	1.000	1.000	0.000
3D	5.600	1.095	5.200	1.105	0.2575	0.257	0.364
Sc.	8.800	0.951	8.250	0.786	0.0536	0.540	0.633
Time	124.900	54.690	113.750	64.471	0.5588	0.559	0.187

the degree of freedom ($n + m - 2$ of the t student, where n and m are the number of samples in (or the size of) the first and second population, respectively) for all the rows was 37. The maximum value reached in the answers for each question was 7 points for questions from *Q*1 to *Q*7 and 3D, 10 points for the overall score, and 328 s for the time required to complete the selection process.

Table 3 shows that the results for all the questions do not show statistically significant differences between the two systems when tests were applied, although question *Q*1 is just at the 0.05 limit. In addition, it must be noted the high scores obtained by both systems, in particular in both fun experience and difficulty. Regarding the time required by the participants to complete the test, there are no statistically significant differences between the mobile AR application and the pseudo-holographic system (a mean of 124.9 s for the AR app and 113.75 for the pseudo-hologram, with $t[38] = 0.5588$ and $p = 0.559$, Cohen's $d = 0.187$). In this sense, when the results are displayed in a boxplot (see Fig. 9) the overlapping of both distributions is high, although the data distribution is skewed down for the AR app values, whereas the distribution is skewed up for the pseudo-hologram values. In addition, three singular points arise. The singular points depicted as an asterisk (*) indicate an extreme case where the value is located further than three times the height of the 75-percentile box. The singular points depicted as circles (o) indicate outlier values which are located further than 1.5 times the height of the 75 percentile box. These singular data correspond to tremendously analytical users who required a very long time to select one among all the available choices for each parameter.

To determine whether using one of the two systems first has any effect on the scores for the second system, the sample was divided into two groups (the participants who used AR first and the participants who used the pseudo-hologram first). Paired *t* tests assuming equal variances were applied to the scores given to all the questions. Table 4 shows the means and the standard deviations, according to the order of

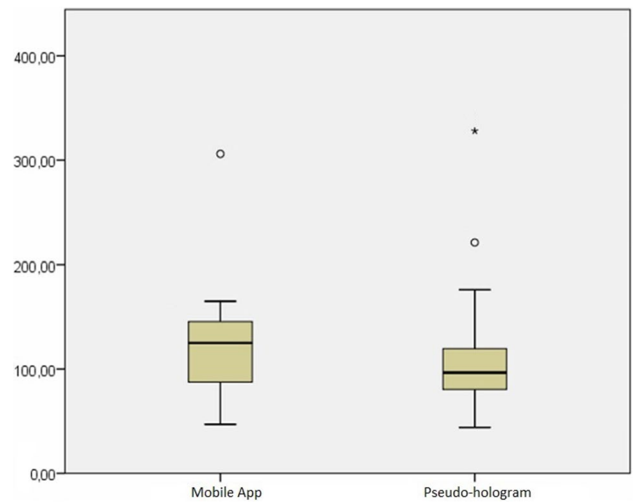

Fig. 9 Time required to complete the test

exposure, for the group that performed the test with the AR app first. Table 5 shows the same values for the participants in Group B (those who used the pseudo-hologram first to perform the test). Although it is not shown in the tables, the degree of freedom ($n + m - 2$ of the t student) for all the rows was 17 in Table 4 and 18 in Table 5. The left-most column of the last two rows in these tables shows the legend "*M*/*M*" for the paired *t* tests of the scores assigned by the users, and the legend "*T*/*T*" for the paired *t* tests of the time required to complete the tests.

Tables 4 and 5 do not show any statistically significant difference in any of the groups. After discussing these results with the users, we found out that the reason for such behavior is that the aspect of the watches was different between both systems. The difference in hue (the colors are much brighter and the models look more contrasted in the AR app, compared to the holographic system, whose effect based on semi-transparent crystals attenuates the color) caused them to study again all the options when using the second system

Table 4 Paired *t* tests for group A (participants who performed the test with the AR app first)

	AR		Pseudo-hologram				
	Avg.	SD	Avg.	SD	*T* student	p	Cohen's *d*
*Q*1/*Q*1	6.65	0.587	6.15	0.876	2.703	0.140	0.684
*Q*2/*Q*2	5.20	1.989	5.55	1.849	− 0.725	0.477	− 0.182
*Q*3/*Q*3	6.45	0.605	6.60	0.598	− 1.143	0.267	− 0.249
*Q*4/*Q*4	6.35	0.933	6.45	0.887	− 0.623	0.541	− 0.110
*Q*5/*Q*5	6.60	0.598	6.60	0.598	0.000	1.000	0.000
*Q*6/*Q*6	6.65	0.587	6.50	0.946	0.719	0.481	0.196
*Q*7/*Q*7	6.10	0.852	5.75	1.209	1.677	0.110	0.340
3D/3D	5.60	1.095	5.70	1.302	− 0.418	0.681	− 0.083
M/M	8.80	0.951	8.49	1.259	1.303	0.208	0.280
T/T	124.90	54.690	119.60	51.415	0.492	0.629	0.100

Table 5 Paired *t* tests for group B (participants who performed the test with the pseudo-hologram first)

	AR		Pseudo-hologram				
	Avg.	SD	Avg.	SD	*T*-student	*p*	Cohen's *d*
*Q*1/*Q*1	6.15	0.933	6.35	0.875	− 1.285	0.214	− 0.221
*Q*2/*Q*2	5.85	1.565	5.85	1.387	0.000	1.000	0.000
*Q*3/*Q*3	6.10	1.586	6.40	1.095	− 0.679	0.505	− 0.224
*Q*4/*Q*4	6.30	1.218	6.00	1.257	1.371	0.186	0.242
*Q*5/*Q*5	5.95	1.146	6.10	0.912	− 0.825	0.419	− 0.146
*Q*6/*Q*6	6.50	1.000	6.60	0.598	− 0.623	0.541	− 0.125
*Q*7/*Q*7	6.10	0.968	6.25	0.851	− 0.825	0.419	− 0.165
3D/3D	5.20	1.105	5.20	1.281	0.000	1.000	0.000
M/M	8.25	0.786	8.50	0.946	− 1.157	0.262	− 0.289
T/T	113.75	64.471	114.30	52.312	− 0.079	0.938	− 0.009

(regardless of the group they belong). In fact, 53.85% of the users asked (when performing the second test) if they could change the selection they had made in the first test because they noticed differences in the 3D models in terms of the visualization between the two tested systems, and 38.46% of the users selected a different combination when using the second system. These results do not corroborate our primary hypothesis, because there are not statistically significant differences between our mobile AR application and the pseudo-hologram showcase in terms of usability.

Next, we focus on the results obtained for the user preferences (the answers to the additional questions in the second questionnaire). Figure 10 shows the results (separated by groups) for the first additional question (Which system do you like the most?). Group A was formed by 19 users (48.72% of the population), and seven of these users (36.84% of group A) preferred the pseudo-holographic system, while 12 of them (63.16% of group A) preferred the AR app. Group B was formed by 20 users (51.28% of the total population), and from these 20 users, 13 (65% of group B) preferred the AR app and seven (35% of group B) preferred the pseudo-holographic system. If we study these results by the selected system, from the 39 users, 25 (64.1%) preferred the AR app. From these 25 users, 13 were in group A and 12 were in group B. From the 14 users (35.9%) who preferred the pseudo-hologram, seven of them were in group A and the other seven were in group B. These results validate our secondary hypothesis, since the user preference for the mobile AR application is higher than for the pseudo-holographic system.

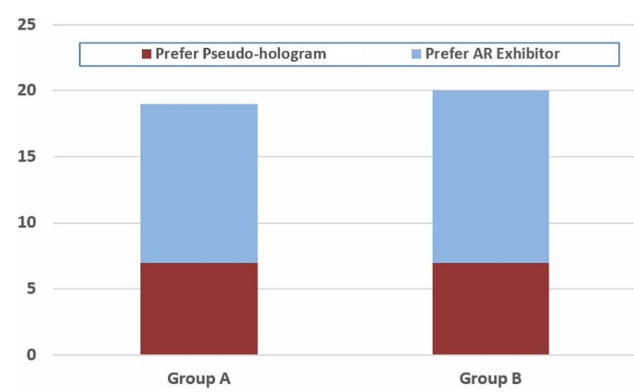

Fig. 10 User preferences for the question "Which system do you like the most?"

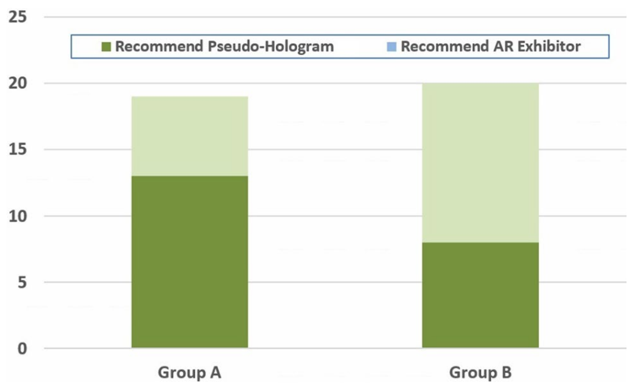

Fig. 11 User recommendation for the question "Which system would you recommend as a virtual exhibitor?"

Figure 11 shows the results for the second additional question (Which system would you recommend as a virtual exhibitor?). In this case, from the 19 users in group A 13 of them (68.42%) recommended the pseudo-hologram, and 6 (31.58%) recommended the AR app. From the 20 users in group B, 12 (60%) recommended the AR app and 8 (40%) recommended the pseudo-hologram. If we study these results by the selected system, from the 39 users 18 of them (46.15% of the total population) recommended the AR app. From these 18 users, six belonged to group A (33.33%) and 12 (66.66%) belonged to group B. From the 21 users who recommended the pseudo-hologram (53.85% of the total population), 13 of them (61.9%) belonged to group A and 8 (38.1%) belonged to group B. Therefore, in this case, it seems to be an inverse relationship between the system tested in first place and the recommendation: almost two thirds of the users who recommended the pseudo-hologram (61.9%) used first the AR app, and exactly two thirds of the users who recommended the AR app as a virtual exhibitor (12 out of 18) came from group B, which tried the pseudo-hologram first. In particular (and unexpectedly), the number of participants from group A that after the end of experiment recommended the pseudo-holographic system is significantly higher than those who recommended this system from group B. From our point of view, the pseudo-holographic system gets a better taste in their mouths than the mobile AR application when the former one is used after the latter one. In addition, we talked with the users to find out why they have voted for the pseudo-hologram (an overall percentage of 53.85% of the users, in front of 46.15% who recommended the AR app). The main reason seems to be that the pseudo-hologram exhibitor was a physical device that may be considered by some an exclusive equipment to be expected in luxury watch retail stores: from the 21 participants of the experiments, 12 of them reported comments that were in line with this idea, including concepts such as exclusivity, uniqueness, and high-end technology. On the contrary, the AR app does not include any physical device except a tablet, a common device not adding any kind of exclusivity. In this sense, we collected user responses such as "This is the high end technology that I'd expect to find if I'd decide to buy a ten-thousand dollar watch in a luxury store", "AR is cool and cute, but even IKEA gets it", or "Luxury watches stores have unique equipment, a smartphone is so casual!".

Next, we present (as an undirected graph) the correlation analysis for the responses given by the participants that tested each system first. The results of this analysis include the correlation factor and the significance level p. Figure 12 shows the significant correlations of the responses given by group A participants. This figure shows that the assigned score is strongly correlated to the responses of interaction ($Q3$), difficulty ($Q6$), usefulness ($Q7$), fun experience ($Q1$), and 3D perception. The latter parameter (3D) is in turn correlated with fun experience ($Q1$) and suitability assigned by participants to use the system in other environments ($Q5$).

Figure 13 shows the significant correlations of the responses given by group B participants. Unlike the results shown in Figs. 12 and 13 shows that the user responses to the different questions are much less correlated. In this case, difficulty ($Q6$) is strongly correlated to ergonomy ($Q2$) and interaction ($Q3$). In addition, suitability ($Q5$) is correlated to interaction ($Q3$) and user satisfaction ($Q4$).

We have also performed a mixed design ANOVA test to find if there is a significant interaction among the different features of the population and their responses to the first questionnaire. In particular, we have considered the factors of gender, age, profession and tested system. A multifactorial ANOVA test revealed that there were only three significant differences: one of them was for $Q4$ (satisfaction) and gender ($F[1,24] = 4.754$, $p = 0.039$, $\eta^2 = 0.165$),

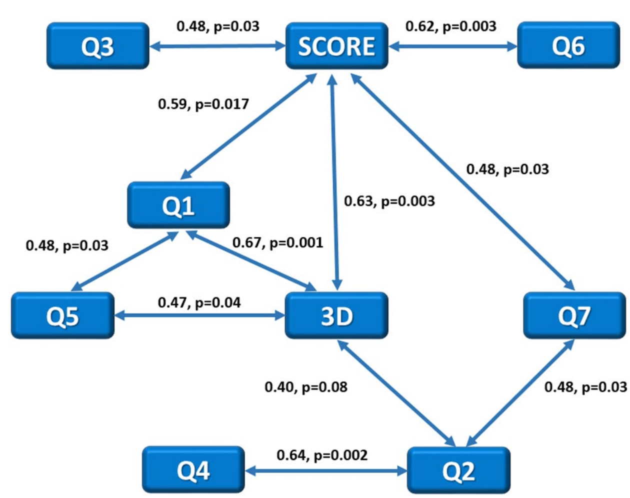

Fig. 12 Significant correlations among the responses given by group A

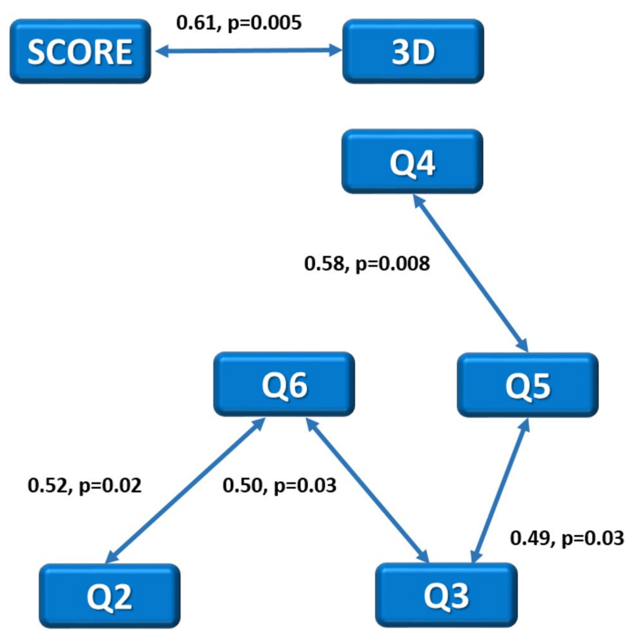

Fig. 13 Significant correlations among the responses given by group B

another one was for $Q4$ and age ($F[4,24] = 3.155$, $p = 0.032$, $\eta^2 = 0.345$), and the last one for $Q5$ (suitability) and tested system ($F[1,24] = 6.936$, $p = 0.015$, $\eta^2 = 0.224$). To illustrate the subsets where significant differences were found, the interaction plot in Fig. 14 shows the results for the satisfaction measured in men and women. Women got less satisfied than men with both systems, and the relative inter-gender differences were the same for both systems. These results are consistent with the existing research on the literature review. In general terms, women appear to be more demanding and expect more from their shopping experiences, especially in the area of beauty, personal care, clothes and luxury accessories [10, 21, 39].

Figure 15 shows the interaction plot for the satisfaction and age differences. In this case, the score was significantly different for the age segment of people in their twenties (17.95% of the population), who scored the pseudo-hologram significantly lower than the rest of the people.

7 Conclusions and future work

In this work, we have developed two multimedia solutions for the creation of virtual exhibitors, and we have carried out a comparative study (based on real users) to measure which system would produce the best impact on users when used as virtual exhibitors in traditional luxury watch retail stores.

The results do not show statistically significant differences between the two systems when tests were applied, both obtaining high scores, in particular in both fun experience and difficulty. The order in which the systems were tested did not show any statistically significant difference in any of the groups. The reason for such behavior is that the color and depth perception experienced by users was significantly different between both systems, making the users study again all the options when using the second system.

Regarding the different features of the population and their possible combinations, the results show that women got less satisfied than men in both systems, and the differences were the same for both systems. In the case of age differences, the score was significantly different for the age segment of people in their twenties, who scored the pseudo-hologram significantly lower than the rest of the people.

The user preferences were significantly different: 64.1% of the users preferred the AR app, in front of 35.9% of users who preferred the pseudo-holographic system, validating our secondary hypothesis. However, most of the users recommended the pseudo-holographic system as a virtual exhibitor (53.85% of the users, in front of 46.15% who recommended the AR app). The main reason is the exclusivity that potential customers associate with the pseudo-hologram exhibitor, in contrast to the common use of smartphones or tablets.

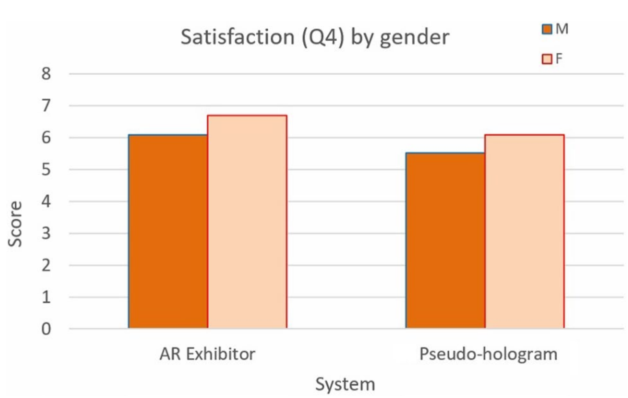

Fig. 14 Satisfaction by gender

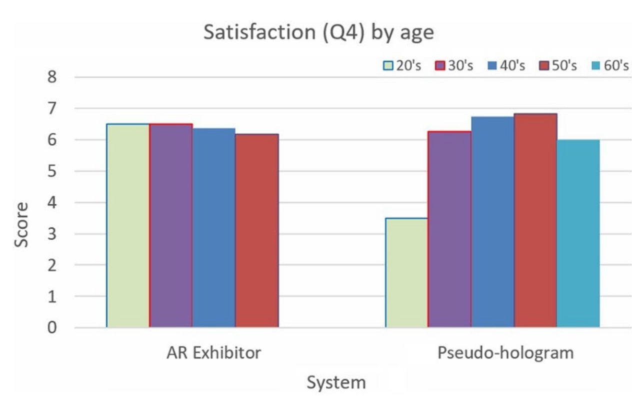

Fig. 15 Satisfaction by age

Nevertheless, this research is limited by the number of participants in the experiment, as well as the number of feasible watch configurations, which in turn could limit the transfer of these results to real retail environments. To overcome these limitations, we plan to develop a transfer roadmap. First, we hope to complete more quantitative and qualitative evaluations at different luxury watch retail stores, producing further empirical evidences associated with both alternatives. Next, we will extend the number of base watches (representing well-known brands in the world of watchmakers), in such a way that the huge number of possible configurations prevent users from completely exploring them in a single session. In addition, we are planning to improve some technical features included in our 3D pseudo-holographic system. In this sense, we have completed the design of a new multitouch user interface, as well as a hand gesture protocol, which once included in the system will allow the users to browse through the different watch collections and configurations. Finally, we plan to carry out a new comparison study including other technologies, such as Virtual Reality (VR) or Mixed Reality (MR).

References

1. Cheoptics 360 (2013). URL http://www.vizoo.com/web/en/cheoptics360/. Accessed on 17 Oct 2017
2. Achille, A.: Digital luxury experience 2017: keeping up with changing customers. Tech. rep., McKinsey & Company, Italy (2017)
3. Anderson, T.W.: Anderson–Darling Tests of Goodness-of-Fit, pp. 52–54. Springer, Berlin (2011). https://doi.org/10.1007/978-3-642-04898-2_118
4. Awad, N., Lewandowski, S.E., Decker, E.W.: Event management system for facilitating user interactions at a venue (2015). US Patent App. 14/829,382
5. Benko, H., Wilson, A.D., Zannier, F.: Dyadic projected spatial augmented reality. In: Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology, UIST '14, pp. 645–655. ACM, New York, NY, USA (2014). https://doi.org/10.1145/2642918.2647402
6. Billinghurst, M., Clark, A., Lee, G.: A survey of augmented reality. Found. Trends Hum. Comput. Interact. **8**(2–3), 73–272 (2015). https://doi.org/10.1561/1100000049
7. Bimber, O., Encarnação, L.M., Schmalstieg, D.: The virtual showcase as a new platform for augmented reality digital storytelling. In: Proceedings of the Workshop on Virtual Environments 2003, pp. 87–95. ACM (2003)
8. Bimber, O., Frohlich, B., Schmalsteig, D., Encarnacao, L.M.: The virtual showcase. IEEE Comput. Gr. Appl. **21**(6), 48–55 (2001). https://doi.org/10.1109/38.963460
9. Bimber, O., Fröhlich, B., Schmalstieg, D., Encarnação, L.M.: The virtual showcase. In: ACM SIGGRAPH 2005 Courses, p. 3. ACM (2005)
10. Blázquez, M.: Fashion shopping in multichannel retail: the role of technology in enhancing the customer experience. Int. J. Electron. Comme. **18**(4), 97–116 (2014). https://doi.org/10.2753/JEC1086-4415180404
11. Bonetti, F., Warnaby, G., Quinn, L.: Augmented Reality and Virtual Reality in Physical and Online Retailing: A Review, Synthesis and Research Agenda, pp. 119–132. Springer International Publishing, Cham (2018). https://doi.org/10.1007/978-3-319-64027-3_9
12. Bonetti, F., Warnaby, G., Quinn, L.: Augmented reality and virtual reality in physical and online retailing: a review, synthesis and research agenda. In: Augmented Reality and Virtual Reality, pp. 119–132. Springer (2018)
13. DArpizio, C., Levato, F., Zito, D., Kamel, M.A., de Montgolfier, J.: Luxury goods worldwide market study, fall-winter 2016. Tech. rep., Bain & Company (2016). URL http://www.bain.com/publications/articles/luxury-goods-worldwide-market-study-fall-winter-2016.aspx.Accessedon2017-11-06
14. Dey, A., Billinghurst, M., Lindeman, R.W., II, J.E.S.: A systematic review of usability studies in augmented reality between 2005 and 2014. In: 2016 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct), pp. 49–50 (2016). https://doi.org/10.1109/ISMAR-Adjunct.2016.0036
15. Dubois, D.: Digital and Social Strategies for Luxury Brands, pp. 327–337. Springer Fachmedien Wiesbaden, Wiesbaden (2017). https://doi.org/10.1007/978-3-658-09072-2_16
16. Elmorshidy, A.: Holographic projection technology: the world is changing. arXiv preprint arXiv:1006.0846 (2010)
17. Fang, H.C., Ong, S.K., Nee, A.Y.C.: Novel ar-based interface for human–robot interaction and visualization. Adv. Manuf. **2**(4), 275–288 (2014). https://doi.org/10.1007/s40436-014-0087-9
18. Gervautz, M., Schmalstieg, D.: Anywhere interfaces using handheld augmented reality. Computer **45**(7), 26–31 (2012). https://doi.org/10.1109/MC.2012.72
19. Goh, D.H.L., Lee, C.S., Razikin, K.: Comparative evaluation of interfaces for presenting location-based information on mobile devices. In: International Conference on Asian Digital Libraries, pp. 237–246. Springer (2011)
20. Hornbaek, K.: Some whys and hows of experiments in human-computer interaction. Found. Trends Hum. Comput. Interact. **5**(4), 299–373 (2013). https://doi.org/10.1561/1100000043
21. Hu, H., Jasper, C.R.: Understanding the shopping experience and its implications for malls as marketing media. J. Adv. Res. **58**(2), 151–164 (2018). https://doi.org/10.2501/JAR-2018-024
22. Jackson, S.: Unity 3D UI Essentials. Packt Publishing, Birmingham (2015)
23. Kern, G.A.: Engineering the Intangible: Strategic Success Factors in the Luxury Watch Industry, pp. 153–180. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-48938-4_11
24. Liu, S., Li, Y., Zhou, P., Huang, S., Chen, Q., Su, Y.: 51–3: a multi-plane optical see-through head mounted display with reverse mode PSLC. SID Symp. Dig. Tech. Pap. **48**(1), 763–766 (2017). https://doi.org/10.1002/sdtp.11739
25. Massey, F.J.: The Kolmogorov–Smirnov test for goodness of fit. J. Am. Stat. Assoc. **46**(253), 68–78 (1951)
26. Matsuda, N., Fix, A., Lanman, D.: Focal surface displays. ACM Trans. Graph. **36**(4), 86:1–86:14 (2017). https://doi.org/10.1145/3072959.3073590
27. Morales, C.: Developing Augmented Reality applications with Unity 3D and Vuforia. eAcademicBooks LLC (2015). URL https://books.google.es/books?id=kUVKCgAAQBAJ
28. Okonkwo, U.: Sustaining the luxury brand on the internet. J. Brand Manag. **16**(5), 302–310 (2009). https://doi.org/10.1057/bm.2009.2
29. Olsson, T., Lagerstam, E., Kärkkäinen, T., Väänänen-Vainio-Mattila, K.: Expected user experience of mobile augmented reality services: a user study in the context of shopping centres. Pers. Ubiquitous Comput. **17**(2), 287–304 (2013). https://doi.org/10.1007/s00779-011-0494-x
30. Onural, L.: Design of a 360-degree holographic 3d video display using commonly available display panels and a paraboloid

mirror. In: Advances in Display Technologies VII, vol. 10126, p. 101260I. International Society for Optics and Photonics (2017)

31. Pachoulakis, I., Kapetanakis, K.: Augmented reality platforms for virtual fitting rooms. Int. J. Multimed. Appl. **4**, 35–46 (2012)
32. Poushneh, A., Vasquez-Parraga, A.Z.: Discernible impact of augmented reality on retail customer's experience, satisfaction and willingness to buy. J. Retail. Consum. Ser. **34**, 229–234 (2017)
33. Rashid, Z., Meli-Segu, J., Pous, R., Peig, E.: Using augmented reality and internet of things to improve accessibility of people with motor disabilities in the context of smart cities. Futur. Gener. Comput. Syst. **76**(C), 248–261 (2017). https://doi.org/10.1016/j.future.2016.11.030
34. Sakamoto, K., Honda, T.: 4-views tabletop flat display system for collaborative work on round table. In: 5th International Symposium on Advanced Optical Manufacturing and Testing Technologies: Optoelectronic Materials and Devices for Detector, Imager, Display, and Energy Conversion Technology, vol. 7658, p. 76582F. International Society for Optics and Photonics (2010)
35. Santos, M.E.C., Polvi, J., Taketomi, T., Yamamoto, G., Sandor, C., Kato, H.: Toward standard usability questionnaires for handheld augmented reality. IEEE Comput. Gr. Appl. **35**(5), 66–75 (2015). https://doi.org/10.1109/MCG.2015.94
36. Schmalstieg, D., Hollerer, T.: Augmented Reality: Principles and Practice. Addison-Wesley Professional, New York (2016)
37. Shapiro, S.S., Wilk, M.B.: An analysis of variance test for normality (Complete Samples). Biometrika **52**(3/4), 591–611 (1965)
38. Tsai, T.H., Chang, H.T., Yu, M.C., Chen, H.T., Kuo, C.Y., Wu, W.H.: Design of a Mobile Augmented Reality Application: An Example of Demonstrated Usability, pp. 198–205. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-40244-4_19
39. Underhill, P.: Why We Buy: The Science of Shopping–Updated and Revised for the Internet, the Global Consumer, and Beyond. SIMON & SCHUSTER (2008)
40. Wagner, D., Reitmayr, G., Mulloni, A., Drummond, T., Schmalstieg, D.: Real-time detection and tracking for augmented reality on mobile phones. IEEE Trans. Vis. Comput. Gr. **16**(3), 355–368 (2010). https://doi.org/10.1109/TVCG.2009.99
41. Wang, J., Qian, L., Azimi, E., Kazanzides, P.: Prioritization and static error compensation for multi-camera collaborative tracking in augmented reality. In: 2017 IEEE Virtual Reality (VR), pp. 335–336 (2017). https://doi.org/10.1109/VR.2017.7892313
42. Yang, T., Lu, Y., Wang, Y.: Novel interactive virtual showcase based on 3d multitouch technology. In: 2009 International Conference on Optical Instruments and Technology: Optoelectronic Imaging and Process Technology, vol. 7513, p. 75132U. International Society for Optics and Photonics (2009)
43. Yaoyuneyong, G., Foster, J., Johnson, E., Johnson, D.: Augmented reality marketing: consumer preferences and attitudes toward hypermedia print ads. J. Interact. Adv. **16**(1), 16–30 (2016)
44. Zhu, W., Owen, C.B., Li, H., hyun Lee, J.: Personalized in-store e-commerce with the promopad: an augmented reality shopping assistant. Electron. J. Commer. Tools Appl. **1** (2004)