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An Augmented Reality Application for Personalised Diamond Shopping

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Abstract- **This paper presents an Augmented Reality (AR) Application (App) developed for bespoke jewellery solutions. The app allows users to experience a visual representation of diamond rings through their mobile device. Hence customers could design and review their bespoke jewellery without having to visit the jeweller shops, and jewellers could communicate changes in real-time, so saving time and money. Adding AR would allow customers to view their bespoke jewellery in place and therefore, gain a better idea of how it would look once completed. Seven participants evaluated the AR App by completing a questionnaire after using the App. The application of Exploratory Factor Analysis resulted in four factors (compatibility, likeability, functionality and usability). Overall, the participants appreciated the AR App; regardless of their gender, age and experience.**

Keywords- diamond jewellery; augmented reality; bespoke shopping; system usability

I. INTRODUCTION

With the rapid development of technological solutions in the 21st century, shoppers expect tailored made solutions that cater to their specific need. Shoppers have become more vocal about their specific requirement in the manufacturing of the products, especially about something as personal as a piece of jewellery. The creation of bespoke jewellery allows shoppers to capture stories that are personal to them. The current process uses modern 3D design and printing techniques alongside traditional metalworking practices to create bespoke jewellery pieces. There is scope to improve this process of consultation, crafting, evaluating and refining of jewellery. At the beginning of this process, clients tend to have an idea for an article of jewellery, but their concept can change when they see their ideas realised. The process of making this jewellery can often be expensive, and little, or no alteration is feasible at the end of the process.

Moreover, our world is becoming more digitised; this has caused a significant shift from the real world (reality) to the virtual world, and this wind of change has also affected shopping. There is a paradigm shift among shoppers preference for online shopping as opposed to the high street. These changes, along with the logistical efficiency among online retailers, have given shoppers less incentive to leave their houses. However, jewellery e-stores have struggled to attract online shoppers as the experience of buying them are more personal to an individual. Some of the difficulties faced by the jewellery e-stores include: how do customers try on their products online, difficulty visualising 2-D items and the inability of 2-D items to provide shoppers with a real sense of the look, size and product details. The outcome of online jewellery shopping can often leave a negative impression of the product. However, combining Augmented Reality (AR) with the existing 3D design models can mitigate these challenges. The clients will be able to visualise the jewellery, judge how it looks on them before ordering it.

AR is "a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view" [1]. It bridges the gap between virtual reality and the real world, and popularly used in visual art, commerce, archaeology, military, navigation, architecture, medical and flight training [2]. There has been increasing attempts over the last few years on the adaptability of AR into the jewellery business, yet the challenges of AR integration with traditional jewellery making methods, development costs, maintenance and resistance to new technology are still there [3]. AR has the potential of assisting shoppers in creating bespoke jewellery, and it provides a virtual picture of how well it looks on them before authorising the purchase. More so, the in-store jewellery sells can be enhanced through the use of AR equipped screens, mirrors and dressing rooms. The use of such solutions will attract and impress more jewellery shoppers.

Recently, modern smartphones can be used as an AR Application (App) platform. Hence, there are more than 2.2 billion AR-enabled smartphones in the market. The Massachusetts Institute of Technology (MIT) has named mobile AR as one of the top 10 emerging technologies [4]. This huge growth has opened new research possibilities in education, business and the creative sectors [5].

Therefore, this study proposes a cost-effective, easy to maintain AR App for delivering bespoke jewellery to the shoppers. The AR App was designed to provide consumers with more realistic product experience and encourage user engagement in the ring design process. The AR App consists of several scenarios which include, the selection of rings, putting a diamond of your choice on the ring, colour and shape selection etc. The shoppers can visualise their bespoke designed ring on their finger via a smartphone. Once the shoppers are satisfied with their design, they can then place the order. Twenty-seven people evaluated the AR App and provided their feedbacks in the form of filling out questionnaires after using the App. The overall results indicated that the users enjoyed using the AR App. Additionally, previous studies have not investigated the system usability of AR App by shoppers. Hence, this study will investigate the user perception of shoppers creating bespoke jewellery with the aid of AR.

This paper is divided into six sections. The related work is presented in Section 2. The research methodology is provided in Section 3. An overview of the AR App is provided in Section 4. The results and discussion are presented in Section 5. Finally, the conclusion and future work are discussed in Section 6.

II. RELATED WORK

This section aggregates knowledge about relevant work to the current study. The concept of AR has been there for many decades; however, it has gained importance in recent years due to technological advancements. The following examples highlight how different sectors have benefited from AR.

A. Education

AR-based learning has been applied in education for aiding the delivery of lessons in several subjects. An example includes' the use of AR in astronomy class for learning the relationship between the sun and earth. The AR system used 3D rendered sun and earth shapes to teach students about their relationship with each other [6]. In biology study, AR has been used to display 3D models of the human organs to students in real classrooms. This enhances the students' knowledge acquisition in the subject area [2]. The SMART (System of Augmented Reality for Teaching) is an educational App developed for teaching school students about the differences in animal types and different modes of transportation. The App used 3D models of different animals and transportation mediums so that students can understand how animals such as a monkey, dog, elephant do differ from each other and how to transport mediums such as a car, bus, the aeroplane differ from each other [7].

B. Museums and Cultural Heritage Sites

In recent years, museums and cultural sites have experimented with the use of AR in their premises. About 35% of the museums in Europe have incorporated AR and Virtual Reality (VR) Apps to enhance their visitor's experience. Visitors can use their mobiles phones for navigation, orientation and interaction with the museum collections [8]. In an interesting experiment, the researchers combined historical photographs with information about a historical street in an AR App. Their experiment results yielded positive feedback from the testing participants as this experiment helped them to get more information about the historical street and made their visit more fun-filled [9].

C. Industrial Maintenance

AR has already been applied in manufacturing, military and industrial settings to help the workers with their regular maintenance activities. For example, military staff can perform their maintenance activity in a bulletproof vehicle conveniently and safely with the help of AR App. The AR App will use labels, texts and arrows to guide workers in carrying out their task. [10].

D. E-Business

Recent research has shown the worth of AR in e-business as with the new generation of consumers (i.e. Millennials), novel methods in sales are crucial to keeping the business up with the times [11]. AR has been tried through virtual fitting rooms to aid customers in their selection of items they do like. As customers can try the item on virtual avatars to inform their decision in purchasing the item [12].

E. Jewellery

A recent study enhanced traditional jewellery with the help of 3D models. They referred to this as smart jewellery. The researchers presented a prototype of the 3D assisted necklace to several test participants online to inquire about their perception of smart jewellery. The results showed that the participants appreciated the idea of integrating traditional jewellery development methods with the latest technological solutions. However, the smart jewellery research field is still underexplored, and there is a need for further studies to investigate this research area [3].

INOVA Diamonds have developed an App that can be used online and in-store, which helps the customers to design their rings. The customers can then take a photo and try the selected ring on a static photo of their hand. The INOVA Diamonds App is not AR, as it only supports a static photo of the hand [13]. On the other hand, Diamond Hedge recently launched "liveAR" App in which customers can try diamond rings on their fingers. However, there is no capacity for developing a bespoke solution [14]. Besides this "Say Yes", "Shop4Rings" and "CaratLane" are examples of other Apps helping customers to try rings on their hands through AR, but these Apps also lack the capacity that enables the user to create bespoke ring designs [15]. Therefore, this paper developed an AR App that enables users to create their designs and try it on their hand via AR.

Additionally, most of the literature review has focused a lot on the designed without much focus on the user experience [16]. In the case of wearable jewellery, investigation of user experience becomes more important as jewellery items are visible to the public and are connected to the image of the individual wearing them [17]. Therefore, the investigation of the users' point of view is an open research area awaiting exploration [18]. This study also explored the user experience of users creating and trying on their bespoke jewellery design via a mobile AR App.

III. RESEARCH METHODOLOGY

This section describes the details and steps of the research methodology used for this study.

A. Study Design

The study design started with workshops sessions with experts in the diamond business. These workshops helped to elicit the system requirements, which defined the scope of work. Prototyping approach was used to develop the AR App, which involved the experts in the field throughout the development process. A user perception questionnaire was developed with the help of literature [19, 20], and ethical approval was obtained from the Faculty of Computing, Engineering and Science research ethics committee.

B. Data Collection

The data collection was carried out over multiple sessions. In total, 27 participants (17 female and 10 male) took part in the testing phase. The data collection part was structured as:

- Participants gave their consent to participate in the testing activity.
- The purpose of the AR App explained to the participants.
- Participants had a chance of hands-on experience with the AR App.
- Participants generated ring designs based on their own choices.
- After testing, participants filled questionnaires related to their perceptions of using the AR App.

C. Data Analysis

Questionnaire data was added into the SPSS 25 to run statistical analysis. Data reliability tests were performed to test the reliability of the data. As per study requirements, Exploratory Factor Analysis (EFA) and Regression Analysis were applied to the data. Data analysis enabled us to evaluate AR App usability considering factors such as instructiveness, ease of use, immersions etc. Details of data analysis and their interpretation are available in section 5.

IV. CONCEPT DESIGN AND PROTOTYPE

The AR App is designed using Unity 5 and developed for multiple platforms, including (iOS and Android). The AR App allows the customer to view a catalogue of rings, select a ring, customise the ring and project a fully rendered 3D model of the ring onto their finger. They can also save the customised ring in their account or the photo gallery for future reference.

A. AR App Scenario

Futura has been used throughout with the use of the capital case for headings. A dark colour scheme has been applied with dashes of red where appropriate. The user can manipulate the textures of three parts of the jewellery (metal, stone and colour) in 3D view.

B. AR App Catalogue

The App catalogue provides example designs, which can be an inspiration for users with no experience of designing bespoke jewellery. The AR App has the following catalogue categories:

- Engagement rings
- Wedding rings
- Men's wedding rings
- Eternity rings

The focus of the AR App is on rings and in particular, engagement rings. With around 70 different engagement rings to select from the prospective customers will be able to pick out a ring or better still customise an existing ring to their individual need. The user can select metal types like gold, silver etc., stone types like ruby, garnet etc. and colour types like red, blue etc., as per their individual needs. After completing the customised ring, the user can project their bespoke ring on their finger through the help of AR, as shown in figure 1.

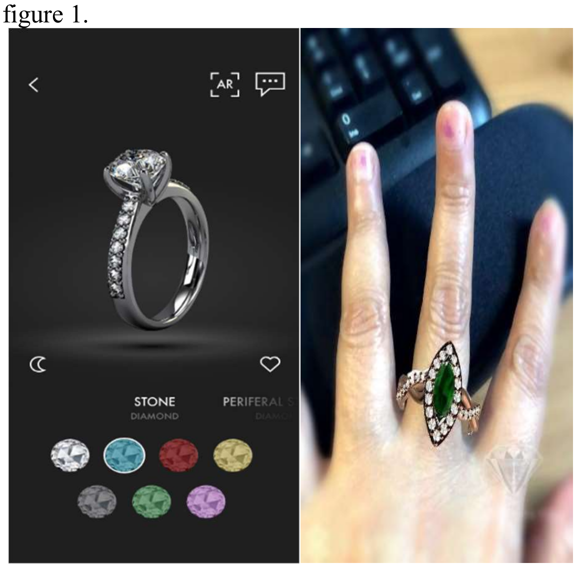

Figure 1. Home Scenario and AR Ring on Finger

C. Order Button

In case of online use, a button has been added to the gallery that will open the default mail client on the device for users to send their customised design. The subject of the email has been set to the name of the ring that the user is viewing in the gallery. The AR App uses Google Firebase to store data so that diamond companies have access to requested rings all the time and for saving client communications.

V. RESULTS AND DISCUSSION

This section presents results from the user testing conducted for this study in the form of descriptive statistics, EFA and regression analysis.

A. Demographics of Testing Participants

In total, 27 participants took part in two testing sessions. Their demographic characteristics are summarised in table 1. During testing, we got participation from both male and female as well as young and middle-aged participants. The testing further had a mix of with previous AR experienced and non-experienced participants.

TABLE I. DEMOGRAPHIC INFORMATION OF SURVEY PARTICIPANTS

Gender	Female	17	63%
	Male	10	37%
Age	<= 25	16	59%
	> 25	11	41%
AR Experience	Yes	9	33%
	No	18	66%

B. Descriptive Statistics

The descriptive statistics help to understand data gathered for EFA. The basic descriptive statistics, including minimum, maximum, mean and standard deviation (SD) values for each variable, are presented in table 2.

TABLE II. DESCRIPTIVE STATISTICS FOR SURVEY VARIABLES

Question	Min	Max	Mean	SD
Q1	1	5	4.333	0.734
Q2	1	5	3.852	1.064
Q3	1	5	3.963	0.706
Q4	1	5	4.259	0.764
Q5	1	5	4.259	0.764
Q6	1	5	4.407	0.694
Q7	1	5	4.444	0.641
Q8	1	5	4.444	0.641
Q9	1	5	3.963	0.808
Q10	1	5	4.370	0.839
Q11	1	5	4.444	0.641
Q12	1	5	4.519	0.580
Q13	1	5	4.556	0.641
Q14	1	5	4.370	0.884
Q15	1	5	4.370	0.792
Q16	1	5	4.370	0.742

The minimum and maximum values range from 1 to 5 for each variable. Mean is widely used as a valid measure of central tendency. The mean values for the current survey varied between 3.852 and 4.556. Hence, most of the responses are on the positive side of the scale. SD is a vital measure of dispersion that provides the idea about how far the response values deviates from the mean. The SD values for this study ranges from 0.580 to 1.064, which means that these values are strongly grouped around the mean.

C. Exploratory Factor Analysis

The EFA method is used as it *"uncover the underlying structure of a relatively large set of variables"* [21]. The EFA helps to identify and explore factors for questionnaires and finds associations between these factors [22]. The Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) is used to explore whether the sample size is sufficient for extracting factors. Usually, KMO values larger than .60 are considered good [23]. For the current study, the KMO value of .713 means the dataset is adequate for the EFA.

Varimax rotation is used through the Principle Component Analysis (PCA) model; four factors were extracted using the Kaiser criterion of eigenvalues greater than one as recommended by literature [24]. The EFA results are summarised in table 3.

Factor 1 accounts for 22.569% of the variance, Factor 2 accounts for 22.374%, Factor 3 accounts for 16.928% and Factor 4 accounts for 15.463% of the variance. The total variance explained by the four extracted factor is 77.335%, which is well above the acceptable limit of 40% [25].

TABLE III. IDENTIFYING THE UNDERLINE FACTORS USING ROTATED COMPONENT MATRIX

Factors	Questions	Factor Loadings	Factor Mean	SD	Eigen-value	% of Variance	Cumulative %	Cronbach's Alpha
F1 Compatibility	The App function locates and recognises the scene precisely (i.e. objects in the real and virtual worlds are properly aligned with each other).	0.809	4.20	0.698	7.836	22.569	22.569	0.721
	The App provides useful content to make a decision.	0.764						
	The App replicates the in-store experience.	0.747						
	The App enriches the real world by combining real and virtual information.	0.675						
	The App can act as a better advertising and marketing tool.	0.543						
F2 Likeability	I like the concept of digitising jewellery products through AR.	0.808	3.71	0.555	1.787	22.374	44.944	0.807
	I think this App will have a value-added impact on the jewellery business.	0.799						
	I like the concept of controlling the content with hands.	0.722						
	The App helps differentiate the business from competitors by providing more customised shopping experience.	0.64						
	I think the App can provide an efficient shopping experience.	0.573						
F3 Functionality	The App offers many features.	0.848	4.37	0.688	1.567	16.928	61.872	0.770
	The App offers a pleasant shopping experience.	0.71						
	The App offers more interaction and is fun to use.	0.535						
F4 Usability	The App works properly.	0.840	4.19	0.801	1.183	15.463	77.335	0.635
	The App is easy to use.	0.668						
	I think I will recommend this App to others.	0.615						

The Cronbach's Alpha values for Factor 1 to Factor 4 ranges from 0.917 to 0.926, indicating a high level of internal consistency [26]. The factor loading for all 16 variables ranges from 0.535 to 0.848. These are greater than .40, which is the literature accepted minimum loading [27]. The factors naming is done based on the nature of variables that loaded in each category. Factor 1 was called compatibility; Factor 2 was called Likeability, Factor 3 was called Functionality and Factor 4 was called Usability.

Factor 1 (Compatibility): Compatibility means the AR App is consistent with the user needs. The variables belonging to this factor help the users in decision making by combining real and virtual world objects, replicating in-store experience and recognising the scenes precisely.

Factor 2 (Likeability): This factor refers to the liking of the AR App from users' point of view. Likeability is often cited as an important factor for technology success [28]. Within this factor, the users liked the concept of jewellery digitisation, content controls with hands, customised and efficient shopping experience.

Factor 3 (Functionality): This factor refers to features offered by the AR App. Having multiple features in a single App is usually useful. The users appreciated pleasant shopping experience through AR, interaction and fun-filled usage of the AR App.

Factor 4 (Usability): This factor refers to system usability from the users' point of view. The usability of the AR App is measured through variables like; ease of use, proper working and recommendation of the App to others.

D. Factors Impact on AR App Usability

This section explores the impact of different factors on AR App usability through linear regression. The relative impact of different factors will highlight their relative importance to user usability. The statistical results are summarised in table 4.

TABLE IV. FACTORS IMPACT FOR USABILITY THROUGH LINEAR REGRESSION

Factor	F4 (Usability)					
	β		t		P	
F1	0.681		4.153		0.000***	
F2	-0.179		-1.044		0.307	
F3	0.332		2.163		0.041*	
Model Summary						
	R	R2	Adjusted R2	S.E	F	P
F4	0.766	0.587	0.534	0.555	10.914	0.000***

Note: $p<0.001$*** = highly significant, p< (0.01** & 0.05*) = significant

In the model summary, the value of R^2 indicates that 58.7% of the variability in average usability can be explained by all the factor, respectively. The F test has high significant values, which indicate that there is a linear relationship between the variables, which shows that the model is the best fit for usability. According to the result, the F1 has the highest significant impact (0.000***) on the AR App usability with $p<0.001$ values, which means the AR App's compatibility with users' needs contribute most significantly towards its usability. F3 has a significant impact (.041*) on AR App usability with $p<0.05$, which means the AR App has many features and functions which contributes significantly towards its usability. However, F2 have no significant impact on the AR App usability; meaning the users were less concern about the likeability of the App, other factors such as F1 and F3 were more important to them.

E. Demographics Impact on AR App Usability

In addition to the overall factor impact analysis, this study further explores the impact of demographic characteristics of the survey participants. There are two points of views in the literature about demographics impact on technology success. Some researchers believe that demographic characteristics of the participants such as gender, age groups etc. have a strong impact on technology success and adaption [29, 30]. Whereas the other group of researchers believe that, the demographic characteristics of the participants do not affect technology success and retention [31-33]. Therefore, it would be interesting to explore whether demographic characteristics of our participants affect AR App usability or not.

The questionnaires used for this study gathered data on a Likert scale, which is ordinal rather than interval, and such data usually does not follow a normal distribution. As the data set is smaller than 2000 values, Shapiro Wilk Test is applied.

The test indicates that all demographic characteristics, including (Gender, Age, AR Experience) have significant values ($p<0.001$), which means data is not normally distributed. Therefore, to check the difference between different groups of data, some non-parametric test should be used instead of the sample t-test. Hence, the Mann Whitney U test is used for testing the difference of demographic characteristic variables on the dependent variables because they have only two possible values (gender: male or female, etc.). Table 5 summarises results for the demographic characteristics of the testing participants.

Gender: The gender-based results in table 5 show the relative impact of gender on usability. In the testing, 17 females and 10 males participated. The Mann Whitney U test results show that all values are insignificant ($p> 0.05$) based on the gender of the participants. Therefore, we conclude that the gender of the participants does not have a significant impact on App usability.

Age: The age-based results show the relative impact of participants' age on usability. There were 16 participants with age group <= 25 years and 11 over the age of 25 years. Again, the Mann Whitney U test results show that all values are insignificant ($p>0.05$) related to the age group of the participants. Therefore, we conclude that the age group of the participants do not have a significant impact on App usability.

TABLE V. MANN WHITNEY U TEST RESULTS FOR DEMOGRAPHICS

Demographics			F1	F2	F3	F4
Gender	Male	Mean Rank	15.235	14.176	15.647	15.471
	Female		11.900	13.700	11.200	11.500
	Mann-Whitney Asymp. Sig.		0.249	0.850	0.121	0.172
Age	<= 25	Mean Rank	14.44	13.69	13.69	14.72
	> 25		13.36	14.45	14.45	12.95
	Mann-Whitney Asymp. Sig.		0.705	0.757	0.785	0.537
AR Experience	Yes	Mean Rank	9.44	13.22	12.22	10.33
	No		16.28	14.39	14.89	15.83
	Mann-Whitney Asymp. Sig.		0.021*	0.651	0.364	0.065

Note: p<0.001*** = highly significant, p< (0.01** & 0.05*) = significant

Previous AR Experience: The results based on participants having previous AR experience is shown in table 5. There were 9 participants with previous AR experience, whereas 16 didn't have AR experience before. Only F1 has a significant value of 0.021* which means AR experience does impact compatibility factor. Other factors have insignificant impact values, therefore not contributing any impact on App usability.

In general, gender, age and previous AR experience do not influence participants' point of view on AR App usability. Therefore, we can conclude that the results of this study are consistent with the second group of researchers, who believe that the demographic characteristics of the participants do not affect technology success and usability. The survey participants in this study liked the AR App and enjoyed the experience of using it regardless of their demographic characteristics. However, to generalise these results, there is a need for more user testing sessions with the potential users, which will help to improve quality of the AR App and increase its impact on the shopping experience of the users.

VI. CONCLUSION AND FUTURE WORK

This paper presented a mobile-based AR App, which offers customised, pleasant and fun-filled shopping experience for jewellery shoppers. The users can install AR App on their phone and use the App to create a bespoke ring from the comfort of their home. The user can use the AR App to see how the bespoke ring looks on their finger. Afterwhich, a final purchase order is put through to the jeweller.

The user testing performed for the study identified four factors (compatibility, likeability, functionality and usability). Further analysis revealed that most of the test participants appreciated the AR App regardless of their demographic characteristics. Future work should focus on increasing the options for rings, metal and diamond selections and incorporating the ability for the users to share their designed rings on social plate form like Facebook, WhatsApp etc. There is also a need for further user testing, which will help to improve the quality of the AR App.

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