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Exploring the Impact of an Augmented Reality Application for Bespoke Musical Instruments

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***Abstract*- Bespoke products have gained utmost importance among shoppers in recent years. In this paper, an Augmented Reality (AR) application is presented that can be used to market bespoke musical products such as drums. The AR application allows the users to experience a visual representation of custom-made musical drums through the help of their mobile phones. The AR application enables users to design, modify and review bespoke musical drums without visiting a musical instruments workshop. They could also communicate the alterations in real-time, saving them money and time. AR would also allow the customers to view their bespoke musical drums in their rooms or studios to visualise how the drums will look once they are designed. The AR application was tested by 25 participants, who used it to create their bespoke solutions. The System Usability Scale (SUS) and Confirmatory Factor Analysis showed that the AR application received positive feedback from the participants and has the potential to aid the online personalised shopping experience.**

Keywords- Augmented reality; Musical drums, Bespoke solutions; System usability

I. STUDY BACKGROUND

The technological advances of the 21st century have changed shoppers' expectations. Now, shoppers expect to have tailor-made solutions that fulfil their specific needs. Shoppers also have become vocal about their particular requirements in product manufacturing, especially when it comes to the products that are personal to them. Musical drums are one of the products that people feel is unique to them, and they have a lot of attachment to such products. However, the current procedure of designing and manufacturing musical instruments is a traditional product design process, and there is little or no input from the shoppers [1].

Similarly, the manufacturers who offer bespoke solutions for musical drums have to face many challenges. At the start of custom musical drums manufacturing, the clients tend to have few ideas about the things in their minds, and their requirements can change over time. Once some artefacts of the musical drums have been developed, it is challenging and expensive to alter the artefacts as per customer requirements. Therefore, there is scope to improve the bespoke musical drums consultation, design, crafting and refining process.

A. Challenges for Bespoke Solutions

The world is becoming more digitised, which has shifted the real world (reality) into the virtual world (virtual models of things). Digitisation has also affected the traditional style of shopping. Online shopping has become more popular than high street and in-store shopping. The recent crisis of Covid-19 has also contributed to a paradigm shift among shoppers to prefer online shopping. The Covid-19 restrictions and online retailers' logistical efficiency have enabled people to shop from their homes.

However, it has been challenging for musical instrument manufacturers to attract online shoppers, as buying bespoke instruments is more personal to the shopper. The online-bespoke musical instrument manufacturer faces many challenges. The biggest challenge is how does the shopper try their bespoke products online? Most of the items are designed using 2-D technologies using pictures from multiple angles. 2-D objects cannot give the shopper a real sense of the product's size, looks and details [2]. However, the combination of Augmented Reality (AR) and 3D design models to create bespoke solutions has the potential to mitigate these challenges. This combination lets the shopper visualise and judge what their custom-made musical drums look like in their home setting before confirming their purchase.

B. Potential of Augmented Reality

AR has the potential to bridge the gap between the real world and Virtual Reality (VR). AR is "a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view" [3]. The AR applications can be found in education, training, medical applications, military and navigations systems, commerce, visual arts and entertainment [4]. Within the musical domain, AR applications have been used to teach the playing of various musical instruments like drums, piano and guitars [5]. However, we could not find an example from the literature on AR application designing and manufacturing such musical instruments. We believe that AR can potentially assist shoppers in designing and creating bespoke musical instruments such as drums. It can provide the virtual visualisation of how the bespoke designed product will look after its development. Additionally, through the help of AR, the shopper can project the custom-made musical drum in their home or studio setting, giving a sense of that instrument being there.

Most smartphones can run AR applications, making the AR technology cost-effective. According to the Massachusetts Institute of Technology (MIT), smartphone-assisted AR technology is among the top ten emerging technologies worldwide [6]. Additionally, there are more than 2.2 billion AR-enabled smartphones worldwide, which means there is a high chance of growth in AR-related applications for bespoke solutions [7].

Many researchers have applied AR solutions to improve the quality of lessons in educational settings [4]. AR has been used at museums and cultural sites to improve visitors' experience through smartphones [8, 9]. Manufacturing industries and military settings have used AR applications (labels, texts and arrows to guide workers) to help with maintenance activities [10]. Some virtual fitting rooms have been developed to help customers choose the size of the items they wish to buy with the help of virtual avatars [11].

Our research group at The Centre of Excellence in Mobile and Emerging Technologies (CEMET), University of South Wales, is considered one of the pioneers in utilising AR technology in different research domains. Recently, we have experimented with AR animated characters to teach children in primary schools [12]. The experiments showed promising results, and children taught through AR technology enjoyed their lessons and retained more knowledge than traditional teaching methods [13]. We have also applied AR to tailor customers' experiences for diamond shopping. In this AR application, the customer can design their customised diamond ring, try the ring on their hand, and place online orders. The AR application helped the customer get their bespoke diamond ring without the need to visit the store in person, which was highly appreciated in the user testing of this AR application [14].

C. Research Gaps

The academic literature on bespoke solutions shows that most studies have focused on product design without end-user experience [15]. However, in the case of bespoke solutions for musical instruments, we believe that such items are personal to the users and showcase their image to their friends and the public [16]. Therefore, it is imperative to consider the participation of end-users in bespoke product design studies [17]. Additionally, end-user testing of customised products is another area which needs further research [17].

D. Proposed Solution

Considering the needs of the new generation of millennials as the potential consumers, recent research has emphasised the importance of using technical solutions such as AR for an online business to keep the business up with the time [18]. Thus, this paper is focused on proposing a cost-effective AR application for the bespoke design and development of musical drums. The AR application aims to assist the shopper in a realistic product design experience and encourage their engagement in product design. The AR application has many scenarios, including selecting drums, colour, material, size and design, etc. Once the shopper is satisfied with the product, he can place an order. The AR application usability has been evaluated through 25 participants through user testing. The participants filled out SUS and sense of immersion questionnaires after their experience with the application. The results are promising, indicating the scope of using such AR applications in the bespoke musical instruments industry.

II. RESEARCH METHODOLOGY

This section describes the systematic user-centred research process used for this study.

A. Requirements Workshops

The AR application for this study followed a co-design research process, which involved collaborating with researchers, developers, end-users and musical instrument industry experts [19]. The research process started with the requirements workshops, which helped understand the needs of the end-users and the businesses. The iterative workshops also generated a work scope for the project.

B. Prototyping Approach

Based on the nature of this study, the prototyping approach was best suited for the prototype development. This approach was applied with the help of agile methodology, which involved multiple research and development sprints. The prototyping and agile combination allowed the involvement of experts and end-users throughout the research process [19].

C. Data Collection Process

For end-user testing, the research team used SUS questionnaire and designed a user perception questionnaire with the help of the literature [20, 21]. Multiple user testing sessions were held, in which 25 end-users participated. The data collection activities followed the following structure:

- Written consent was taken from each participant before the testing session.
- The research team explained the purpose of the AR application and how to use it.
- The participants had a chance to have hands-on experience with the AR application.
- The participants designed bespoke musical drums and placed dummy orders online.
- After the testing session, the participants filled out the research questionnaires to register their feedback.

D. Data Analysis

For the SUS questionnaires, the researchers followed the traditional SUS data analysis and interpretation process [22].

For user perception of the AR questionnaires, the data was loaded into SPSS 27 to run statistical analysis. Confirmatory factor analysis (CFA) and Mann-Whitney U tests were performed. Both SUS and CFA helped us evaluate the AR application's usability.

III. DESIGN CONCEPTS AND FEATURES OF THE AR APPLICATION

The AR application (Tarian Drums) is designed using the Unity games engine. The current version of the application is designed for the Android platform. The AR application is available in English and Welsh languages.

A. AR Application Scenario

The Tarian AR application is developed to raise market visibility and increase custom drum sales. The application takes the user through designing a custom drum kit where they can update their choices in real-time and see a digital representation of their design reflect those decisions. At the same time, the estimated cost is revised simultaneously.

There are four scenes used by the Tarian Drums AR application, "Launcher", "TarianScene", and "AR". The Launcher scene pre-loads data and then loads into the main TarianScene. Pre-loading allows the application to ensure that the connection to Firebase is set up and ready for the application to use before the user can begin interacting with the application. Firebase is a cloud-based application development plateform that enables users to develop android, iOS and web-based applications [https://firebase.google.com].

Within the TarianScene are the core user interfaces that allow the user to design their custom drum; from here, they can also navigate to the AR scene where the user can view the digital representation of their design in reality. They can also save their customised musical drums against their user account for future reference.

B. AR Application User Interface

The Tarian AR application User Interface (UI) starts with a login page backed by the Google Firebase Authentication package (see Figure 1). This allows personalised data to be stored against a user account. Once logged in, the user can see the creating or loading a drum design pages. From here, the user can select to load an existing drum design from saved data or begin the process of creating a new drum kit design. The ability to store a drum design against a user account and load the persistent data again allows users to amend their design later and share their design easily. The advantage for the businesses will be that they have full access to users' saved data. Later, this could be examined to determine trends and user preferences.

Fig. 1. AR Application Login and Drums Selection

C. AR Application Catalogue

The AR application catalogue provides some design examples that can inspire users who do not have experience in designing bespoke musical drums (see Figure 2). The application has the following catalogue categories:

- The users can select either a complete drum kit or an individual drum.
- The user can select a natural wood or exotic wood or view some information about the stave wood process that the business can offer.
- The image representation of stain finishes depends on the wood type, while colour and effect finishes are independent of wood type.
- The camera icon allows the user to upload an image as a wrap for drums.
- The stage view and white view allow the user to edit their custom drum design and see the changes reflected in real-time.

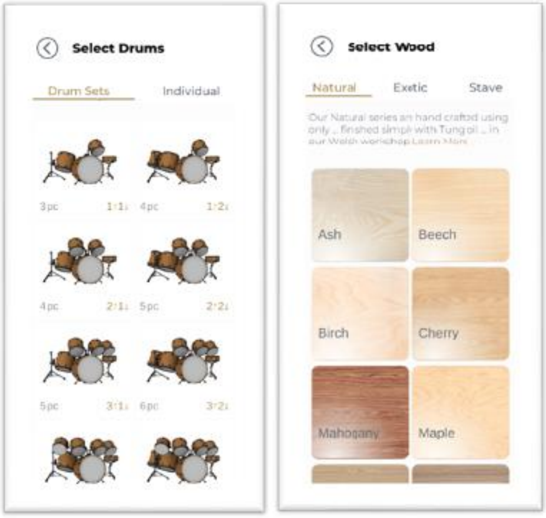

Fig. 2. Drum Kit and Wood Selection

D. AR View and Order Button

AR view loads the AR scene and allows users to place the custom drum in their room. When the user first loads the AR view, the application uses the native AR API (AR Core for Android) to detect surfaces onto which the user can place the drum kit. A digital surface will be displayed to represent these surfaces. Once a user taps a surface, the drum kit will be placed onto that surface (see Figure 3).

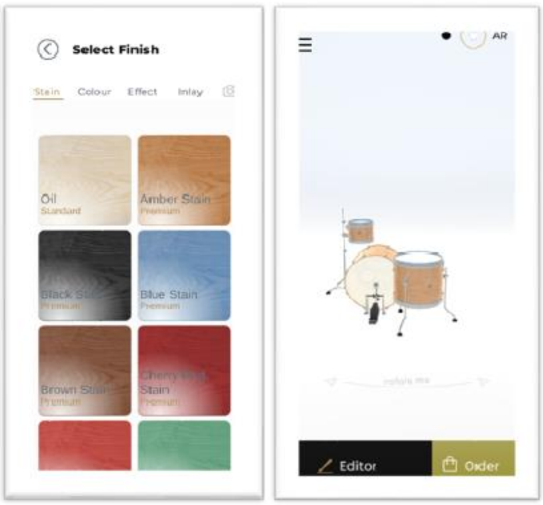

Fig. 3. Finish Selection and AR View

A button has been added in the application to send the bespoke designed drum orders to the business, automatically sending the selected design details to the company's default email. The email's subject will be the name of the user's drum kit from the gallery. The AR application uses Google Firebase to store data due to its availability, reliability, and feature support. The users and businesses will access requested drum kits and their associated communications.

IV. RESULTS AND DISCUSSION

In human-computer interaction (HCI) research, system usability is one of the essential concepts. According to the International Organization for Standardisation (ISO), system usability is "the extent to which specified users can use a product to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" [23]. We evaluated the system usability for this study through SUS and CFA data analysis techniques. This section presents the analysis performed on the data collected from participants through end-user testing. The results' interpretation and relevant discussion are also included to understand the results of this study.

A. Demographics of Testing Participants

To test the usability of the AR application, multiple user testing sessions were conducted, in which 25 end-users participated. The participants' demographics are summarised in Table I. There were 21 male and four female participants. The participants' age ranged from 16 to 62 years. The mean age of the participants is 32.52, with a standard deviation (SD) of 11.89. The age groups are divided into participants younger than 30 years (13 participants) and greater than 30 years old (12 participants). There was a mixture of AR experiences, with 13 participants having had previous AR experience, while 12 participants used AR for the first time.

TABLE I. SURVEY PARTICIPANTS INFORMATION

Gender	Female	4	16%
	Male	21	84%
Age	<= 30	13	52%
	> 30	12	48%
AR Experience	Yes	13	52%
	No	12	48%

B. System Usability Through SUS Data Analysis

We adhered to the standard SUS data collection and analysis process reported in [22]. The SUS questionnaire gave five choices to the participants choose 1 for strongly disagree, 2 for disagree, 3 for neutral, 4 for agree and 5 for strongly agree. The SUS scores are calculated using the following calculations:

SUS Score = (X + Y) x 2.5

X = Sum of the points for all odd-numbered questions – 5

Y = 25 – Sum of the points for all even-numbered questions

As per the academic literature, a SUS score of 68 is considered an average score for such analysis. A score above 68 shows that the system under test offers good usability. However, a score less than 68 means that the system under test has some usability issues which need fixing [22]. For this study, 23 participants scored more than 68, and two participants scored less than 68. This indicates that most participants were happy with the usability of the AR application.

Within SUS analysis, another criteria is known as grading, which allocates different grades to survey participants based on their SUS scores [24]. The distribution of these grades is summarised in Table II. This study's overall average SUS score is 82.83. Based on the criteria mentioned in Table II, this score is equivalent to grade A. This shows that overall, the survey participants enjoyed their experience of using the AR application, and they will also recommend it to others.

TABLE II. GRADING OF SUS SCORES

Grade	SUS Score Range	Meaning
Grade A	>80.3	Excellent
Grade B	68.1 to 80.3	Good
Grade C	68	Okay
Grade D	51.1 to 67.9	Poor
Grade F	<=51	Awful

C. Demographics Impact on the SUS Data Analysis

In addition to overall system usability, this study further explored the impact of demographic characteristics on system usability. In the literature, there are two points of view about the effects of demographic factors on the system usability. The first group believes that demographic characteristics such as gender, age, and experience substantially impact system usability and success of a technology [25, 26]. However, the other group of researchers oppose this point of view and claim that there is no impact of demographic characteristics on the system usability and success of the technology [27-29]. Hence, we are interested in exploring whether the demographic characteristics of our study participants impact the AR application usability or not?

The SUS scores for different demographic characteristics of the survey participants as shown in Table III. Interestingly, each demographic aspect of the participants has an average score of above grade A. The average score for male participants is slightly above that of female participants. The participants above 30 years have slightly above those under 30 years. Similarly, the participants with no AR experience score slightly above those with prior AR experience.

Table III statistics show both segments of gender, age groups and participants with or without previous AR experience scored high on the SUS scale. Therefore, we can conclude that the different demographic characteristics of the survey participants did not play a role in determining their relevant scores. These findings are consistent with previous work on system usability [14, 30, 31].

TABLE III. SUS DEMOGRAPHIC SCORES

Gender	Female	81.88
	Male	84.05
Age	<= 30	83.08
	> 30	84.38
AR Experience	Yes	83.08
	No	84.38

D. System Usability Through CFA.

Descriptive statics are used to understand the data collected for the study. The survey minimum and maximum values ranged from (1 – 5). Mean is used to measure the central tendency of data. The mean values ranged from 3.24 to 4.72, indicating that most responses are on the positive end of the survey scale. SD measures dispersion and how far response values deviate from the mean. The SD ranges from 0.444 to 1.182, indicating that these values are strongly grouped around the mean.

The CFA will highlight important factors that aid system usability, which in our case is the usability of the AR application developed for this study [32]. As a starting point, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is used to check the sample size for factor extraction. A KMO value greater than .60 is considered adequate for such analysis [33]. The KMO value of .727 for this study means that the dataset is sufficient for the CFA to proceed. As per the literature recommendation, the Kaiser criterion of (eigenvalue >1) rule has been followed [34]. The parallel analysis extraction approach resulted in four factors.

After parallel analysis, we ran the SPSS model with four fixed factors. The rotated component matrix is summarised in Table IV. All survey items have acceptable factor loading scores of above 0.40 [35]. The factor mean shows a positive response by the participants. The global Cronbach Alpha value for the whole survey is 0.80, and each factor ranges from 0.62 to 0.81, showing internal consistency [36]. Factor 1 accounts for 23.71% of the variance, Factor 2 for 21.28%, Factor 3 for 17.97% and Factor 4 for 15.62%. The total variance explained by the four extracted factors is 78.63%, which is well above the acceptable limit of 40% [37].

The next step was to name the factors based on the natures of variables loaded against each factor. Factor 1 was labelled as System Compatibility, factor 2 as System Likeability, factor 3 as System Functionality and factor 4 as System Usability.

Factor 1 (System Compatibility): System compatibility means that the AR application is consistent with the users' needs. System compatibility variables support users in their decision-making by merging virtual and real objects, in-store shopping replication experience, alignment of virtual and real objects.

Factor 2 (System Likeability): System likeability refers to users liking the application's features designed to enhance their usability experience of this system [38]. The variables adding to this factor are the contents controlled by the user's hands, digitisation of musical instruments, and customised and efficient shopping experience.

Factor 3 (System Functionality): This factor corresponds to the functions and features incorporated in the AR application. Having multiple features in a single application helped the users to have a pleasant shopping experience through the AR scenarios, activities and interactive interaction with the system.

Factor 4 (System Usability): This factor refers to the actual usefulness and retention of the AR application. The variable within this factor indicates that the users thought that the AR application was useful, easy to use, and worked properly for the intended purposes. Therefore, they will recommend this application to other users.

All resulting factors are consistent with the IOS definition of usability. Additionally, these factors are endorsed by many system usability studies available in the literature [13, 14, 39]. The consistency of these factors means that these can contribute to the experience of the users and can add value to the system's usability.

E. Demographics Impact on CFA.

Similar to demographics impact on the SUS, we want to explore the impact of demographic characteristics on the CFA. We used Mann Whitney U test for this purpose as our survey variables has only two possible answers for gender, age and AR experience. Table V presents the summary of Mann Whitney U test for this study.

The first part of Table V shows the impact of gender on different factors. The Mann-Whitney U test results for both male and female results are insignificant ($p>0.05$). This shows that the gender of the survey participants does not significantly impact the usability of the AR application.

The age group results presented the impact of the participant's age on the usability factors. The Mann-Whitney U test has insignificant ($p>0.05$) values for both age groups. This indicates that the age of the survey participants does not significantly impact the usability of the AR application. Similarly, the Mann-Whitney U test values for the AR experienced, and non-experienced survey participants have nominal values ($p>0.05$), representing that AR experience does not affect the system usability factors.

TABLE IV. CONFIRMATORY FACTOR ANALYSIS

Factor	Factor Loadings	Factor Mean	SD	Eigenvalue	% of Variance	Cumulative %	Cronbach's Alpha
F1	0.821	4.31	0.69	6.63	23.76	23.76	0.74
	0.772						
	0.727						
	0.688						
	0.594						
F2	0.787	3.76	0.58	1.82	21.28	45.04	0.81
	0.743						
	0.716						
	0.675						
	0.598						
F3	0.843	4.29	0.67	1.64	17.97	63.01	0.76
	0.753						
	0.615						
F4	0.824	4.21	0.79	1.23	15.62	78.63	0.62
	0.712						
	0.610						

TABLE V. DEMOGRAPHICS IMPACT ON FACTORS

Demographics			System Usability Factors			
			Factor 1	**Factor 2**	**Factor 3**	**Factor 4**
Gender	Male	Mean Rank	14.983	15.189	14.469	14.815
	Female		11.870	12.430	11.199	11.498
	Mann-Whitney Asymp. Sig.		0.276	0.780	0.137	0.175
Age	<= 30	Mean Rank	13.12	14.01	13.58	13.80
	> 30		12.98	14.91	13.95	11.87
	Mann-Whitney Asymp. Sig.		0.703	0.726	0.817	0.546
A.R. Experience	Yes	Mean Rank	9.56	12.98	11.87	10.51
	No		15.88	14.68	14.73	16.04
	Mann-Whitney Asymp. Sig.		0.082	0.643	0.395	0.073

Note: p<0.001 is highly significant, p< 0.05 is significant

In summary, the demographic characteristics, including gender, age and AR experience, do not influence the participants' point of view about the AR application usability. Hence, these results are consistent with the group of researchers who believe that demographic characteristics have no impact on system usability and success [27-29]. Interestingly, both SUS data analysis and CFA results are consistent with the second research group's point of view. Therefore, we can conclude that overall, the study participants enjoyed their experience with the AR application and appreciated the system's usability regardless of the demographic characteristics.

However, we cannot generalise these results, as only 25 participants participated in this study (low number of participants due to Covid-19 restrictions). There is a need to conduct more user testing sessions with the users to explore their perspectives on system usability. This will help to improve user experience with bespoke AR applications and positively impact users' personalised shopping experience.

V. CONCLUSION AND FUTURE WORK

This paper showcases the development, testing and system usability of the AR application developed for bespoke musical drums. The users can install the AR application on their smartphones and use the application to design from anywhere. The AR application also lets users see the bespoke musical drums displayed in their room or a studio through the AR projection functionality. Once satisfied with the design, the users can order the product through the AR application.

The AR application was tested by 25 participants who participated in the user testing sessions. The participants experienced the application and provided their feedback through questionnaires. The SUS data analysis showed that all participants enjoyed their experience with the AR application regardless of their age, gender and previous AR experience. Additionally, CFA resulted in four essential factors (System Compatibility, System Likeability, System Functionality and System Usability). Further analysis showed that SUS and CFA data analysis results are consistent with existing literature. The findings are also compatible with the ISO definition of system usability.

The future expansion of the AR application can consider incorporating the functionality of sharing bespoke designs created by the user on social media platforms like Instagram, Facebook, Twitter and WhatsApp etc. Adding greater depth to the application’s AR feature would entice regular application use. This can be done by making the AR drums interactive. The use of "virtual buttons" using augmented reality software development kits, such as, Vuforia could allow users via gestures to "play" each drum, receiving audio feedback specific to each drum type. The work on creating accurate auditory representations of each drum based on depth, diameter and material would also significantly add to this experience.

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