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Technological support for novice bamboo woven artisans: potentials and challenges

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Abstract

Weaving flat bamboo strip involves unique skills which take years to master and are often passed along from one generation or artisan to the next generation. This research is an empirical study exploring the use of technology (in particular Augmented Reality, AR, henceforth) in facilitating novice or keen bamboo weavers in learning how to weave. Two different AR interface were deployed to twenty-one designers from architecture, interior design and industrial design fields. The aim is to answer a pertinent question regarding potentials and challenges of using mobile AR in bamboo woven design process, particularly for novice designers. The analysis is two-fold: firstly, related to AR elements and secondly self-reflections of advantages and disadvantages. AR display and other AR related elements are analysed based on ratings given by participant in each interface. Insights are also extracted from the open-ended questions when participants are asked whether they would recommend these two interfaces to other designers or otherwise. The main observed potentials include the ability to see a 360-degree view of the design objects, assembly guide, being able to learn the basic process of weaving and the ability to simulate rapid design iteration. Main challenges include: accuracy, hologram colours and the benefits compared to video tutorials (which were challenged by one participant).

Keywords Augmented Reality, Bamboo Design, Augmented Bamboo Design, Bamboo Craftsmanship and Digital Bamboo Design

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1. Introduction

Highly skilled (flat strip) bamboo weaving artisans acquired their skills through making over years of practice, and often these skills were passed on from previous generations of weavers. Weaving bamboo is commonly used to construct three-dimensional products, turning bamboo poles into bamboo strips approximately 0.1-0.5mm thick and 6-20mm wide. Woven bamboo strips are versatile, especially for constructing curved surfaces such as baskets, bowls, etc., because, unlike the tubular form of a bamboo pole, they are inherently flexible. However, there are some limitations to using bamboo strips. The material in its untreated form is vulnerable to weathering, water penetration, and attack by biological agents such as termites, mould, and other actions which attack untreated wood. It can be treated using chemical agents if increased durability is required. It is also vulnerable to splitting if not constructed correctly due to the unidirectional nature of the fibres in bamboo (which is, after all, a type of large grass). On the other hand, the advance of technology has facilitated the development of bamboo design and bamboo architecture, in particular, the way technology allows manipulation of form, technique and fabrication, which was not possible previously without the support of digital tools. A combination of the two above-mentioned aspects is the point of departure of a series of studies on the use of technology (particularly mobile augmented reality, due to its lower capital investment compared to augmented reality headsets) for novice or non-expert bamboo woven enthusiasts. This paper aims to understand the extent of the positive impact on the utilisation of mobile AR through feedback provided by bamboo enthusiasts during the empirical data collection. This study is part of a more extensive study to catalogue woven joints and serves as a comparative interface study of two mobile AR interfaces for future utilisation. The research question the authors seek to answer is, *"What are the potentials and challenges of using mobile AR in the bamboo woven design process?"* This paper is structured as follows: 1) Relevant literature in the use of technology for design and architecture and subsequently in bamboo design, 2) Methods of empirical data collection, 3) Results of the data collection, 4) Discussion hinged on the two different user interface designs, and lastly 5) Conclusions will be drawn for future studies.

2. Related literature

2.1 The use of technology for design and construction

Digital design embraces the use of digital media in the design process or architectural design process; in other words, computer tools. In the architecture field, this can be traced back to the 1960s, with the rise of utopian thinking such as The Fun Palace project (by Cedric Price and

Joan Littlewood) and Sketchpad developed by Ivan Sutherland in 1963. In 1969, Gordon Pask examined common philosophy of architecture and cybernetics, the first attempt to connect both fields. Digital architecture as a design field was first theorised by Oxman and Oxman (2014), in an edited book containing essays from pioneers in this area. The term digital design is often confused with related terms such as computational design. Briefly, computational design uses computation and its power (to evaluate and to calculate) in the design process, as opposed to merely using digital tools as 'electronic drawing boards' as in digital design. Menges and Ahlquist (2011) provided a seminal edited book on computational design when the design approach's foundation was first conceived. Caetano et al (2020), in their contextualisation of computational design, state that the computational capabilities of computational design offer 1) automating design procedures, 2) parallelising design tasks and effectively managing large amounts of information, 3) incorporating and propagating changes in a quick and flexible manner, and 4) assisting designers in the form-finding process with the use of automated feedback. Three interrelated areas, as outlined by the authors, are: parametric design, generative design and algorithmic design (ibid). Digital fabrication is a method which uses digital data to direct a manufacturing process (Dunn 2012). It is classed according to the techniques acting upon the physical and/or chemical properties of the materials used. There are several types of fabrication: additive procedures, subtractive procedures and formative procedures. Digital fabrication includes laser cutting, CNC milling and routing, rapid prototyping, 3D scanning and robotics. These tools' functions are to transform the digital object into physical parts that can be assembled, thus becoming an object. Augmented Reality (AR) and Virtual reality (AR) technology have expanded design and architecture's design ecosystem, mainly by adding tools to experience and gamify design. Wang and Schnabel (2008) posit that these new 'realities' merge with or replace parts of the physical world. From the previous observation in the authors' previous projects, potentials of VR application in architecture include (but are not limited to): immersive designing in design studio pedagogy setting, participatory urban design as a social VR instrument, spatial prototyping, aiding client-designer conversation, remote site visit, and understanding spatial experience with eye-tracking. Observed AR potentials using mobile or head-mounted displays include: augmented co-design studio, assembly guidance system, holographic construction, gamification experience and remote collaboration.

2.2 Technology implementation in bamboo

With the plethora of support mentioned above in designing, contemporary digital technology in architecture and design has provided the possibility to incorporate computational design into bamboo weaving design practice. Related studies in adapting weaving structures include Huang et al (2016) in lightweight weaving spatial structural systems. The study aimed to facilitate the construction of organic architectural forms through the concept of weaving. However, this adaptation is limited to lightweight indoor and outdoor temporary structures rather than load-bearing structures. Additionally, the computational weaving grammar of traditional Indonesian patterns, particularly patterns originating from West Java, was explored in Harnomo and Indraprastha (2016)'s work. Two types of common woven patterns, biaxial single pattern and biaxial double pattern were analysed. The authors suggested the similarity of a woven pattern with a ruled-based system of a generative algorithm. They also posited that the study is hoped to preserve the traditional weaving method. It can also be argued that the utilisation of contemporary digital technology allows explorations which were not possible without, for instance, producing quick design iterations using parametric design tools or structural simulations. In this endeavour, the authors of this paper investigate the potentials and challenges that arise from the use of AR in design and assembly processes, in particular with the utilisation of mobile AR. AR is expected to contribute to the proliferation of woven bamboo design, especially for non-experts who are keen to acquire handicraft knowledge through the assembly process.

3. Methodology

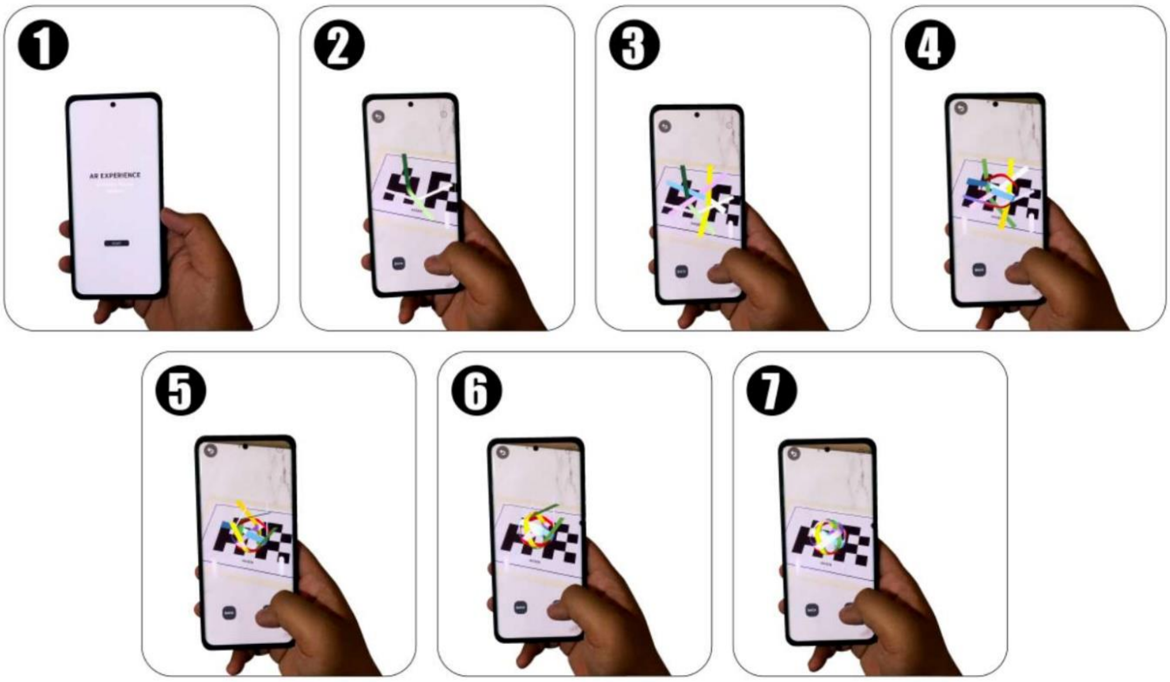

Figure 1. Experiment 1's interface

Two mobile AR interface prototypes were deployed to a group of designers in Surabaya, Indonesia. They are non-expert or novice designers who had never done bamboo weaving prior to joining this study. The first AR interface which was developed in Unity© was deployed for an Android device and was labelled as a 'ball making' experiment or Experiment 1 as participants were asked to follow a custom-made UI (User Interface, henceforth) which includes an interactive step-by-step weaving process to create a ball. The process had weaving strips in two-dimensional form and subsequently turned into a three-dimensional ball, see Figure 1. The transition from two to three-dimensional was also aided by the use of the UI. The second UI uses a commercially available app, Fologram©, which is linked to three-dimensional software Rhinoceros7© to allow exploration of parametric design, see Figure 2. The second interface uses the app to develop the designers' own design by adjusting the design parameters, this interface was labelled 'lampshade making' experiment or Experiment 2. There was no step-by-step feature in the second interface. A total number of 21 designers contributed to the study voluntarily, and consent was taken prior to the experiment. After the completion of two tasks, each designer was asked to try both UIs and to rate their experience using an online questionnaire. The visual display preference is adapted from Van Krevelen and Poelman (2010)'s study, and four elements are included (environment tracking, user movement tracking, user interface and user-friendliness); totalling 16 elements to be rated. Separate ratings scoring sheets were given for Experiment 1 and Experiment 2.

Figure 2. Experiment 2's interface

Reflections from the researchers during the data collection process indicated that UIs could be enhanced for the next research. The different colours of strips in Experiment 1 were designed to ease the following of the provided steps. However, the colours perhaps can be rectified as it was difficult to look at, especially in a bright environment due to the high contrast. Experiment 1 with the assembly stages was hypothesised to be higher in rating in comparison to Experiment 2 due to its assembly feature.

4. Results

Of 21 participants, 76% were male, and 24% were female. Most of the participants (76%) had 4-7 years of design experience, while the rest (24%) had up to 4 years. None of them had more than 7 years of experience. This declared number of years includes their undergraduate study, which is explicitly mentioned in the online questionnaire. Figure 3 shows the distribution of design disciplines which the participants work in, with 'architecture' as the main design field (76%); other disciplines include industrial design and interior design.

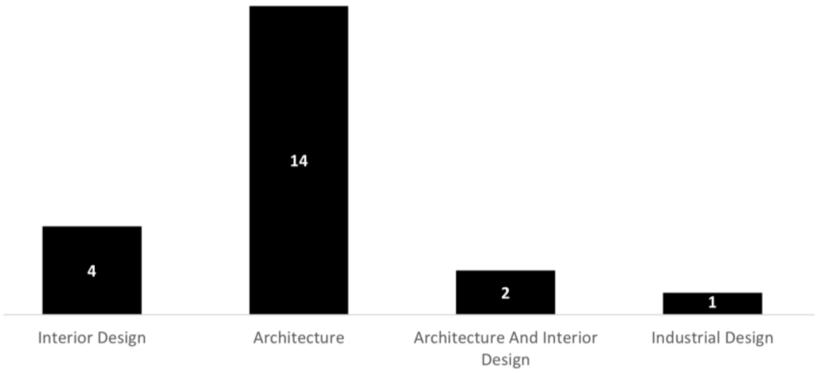

Figure 3. Design disciplines distribution

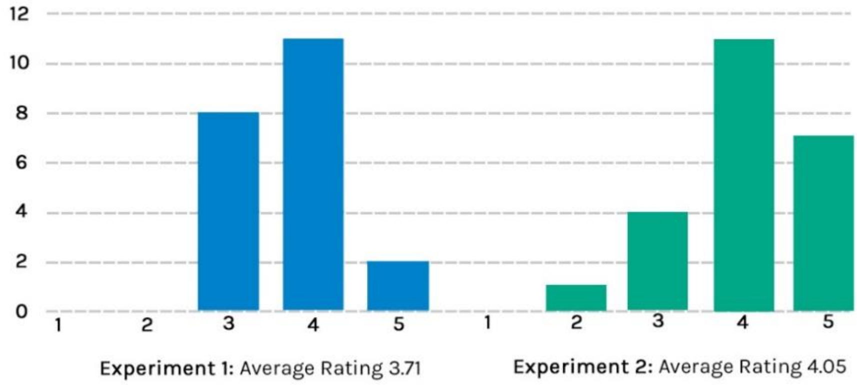

Figure 4. Rating comparison between Experiment 1 and Experiment 2

A comparison between Experiment 1 and Experiment 2's (Figure 4) illustrates that, in general, participants favoured the second experiment, the 'lampshade making' over the first experiment, the 'ball making'. This was in contradiction with the researchers' observations during data collection, as hypothesised in the previous section. Preferences in 'lampshade making' are more diverse compared to the 'ball making' with distribution to rating 3 and above. P2 (Participant 2), who rated 2 for the overall experience of Experiment 2, mentioned that *"Instructions from the AR were not clear (only 3D modelling). Also the surface tracking and scaling were not* *working perfectly"* which might suggest that the step-by-step in Experiment 1 provided meaningful support compared to being able to parametrically tweak the design. This also gives an indication that assembly capability for mobile AR is as significant as being able to simulate multiple designs rapidly in Experiment 2. From the summary (Figure 5), the two lowest ratings across the two experiments are 'colour' and 'eye strain'.

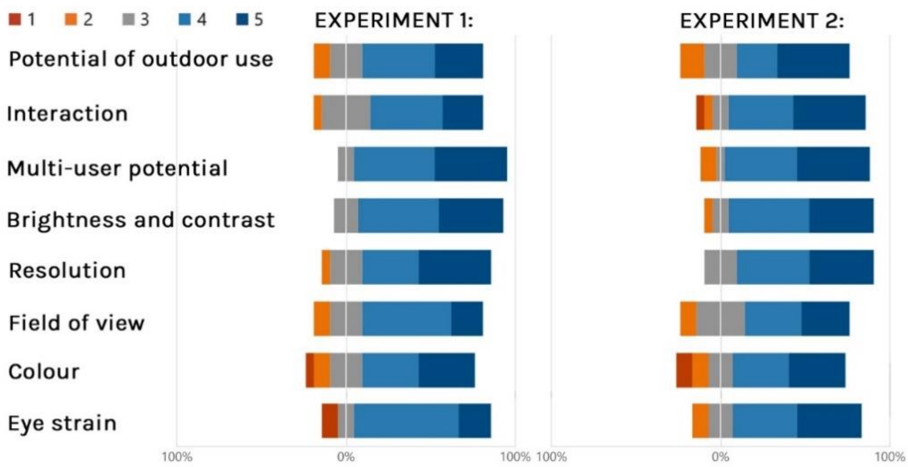

Figure 5. Summary AR visual display's rating comparison

5. Discussion

Gender	
Type	**Label**
Male	1
Female	2

Experience	
Type	**Label**
Up to 4 years	1
4-7 years	2

Complete_task	
Type	**Label**
15 - 30 Mins	1
30 - 45 mins	2
< 15 mins	3

Area_design	
Type	**Label**
Interior Design	1
Architecture	2
Architecture And Interior Design	3
Industrial Design	4

Figure 6. Index labelling dependent variable

In Experiment 1 and Experiment 2, the average time spent was between 15 to 30 minutes. From the descriptive analysis of Experiment 1 (Figure 7), correlations between elements (each visual AR display and other types) can be inferred. The highest is the correlation between 'user friendliness' and 'user interface' (0.834), followed by the same element ('user friendliness') with 'user movement tracing' and 'resolution'. The second highest correlation is between 'resolution' and 'brightness and contrast', 0.807. The other correlations are made aware that 'eye strain' is related to the 'resolution'. These correlations confirm positive relationships between AR display elements and other elements (user interface and user-friendliness). Considerably high correlation between 'resolution', 'brightness and contrast', and 'eye strain' suggested that better resolution with a viable balance of brightness and contrast can help artisans reduce eye strain's impact. Although the use of mobile AR is less taxing for the eyes compared to stand-alone headsets such as Microsoft© Hololens 2, in which the display is right in front of the user's eyes, eye strain is a consideration which needs to be taken into account. This impacts how the assembly processes in Experiment 1 can be better displayed. The item 'colour' has been disregarded as it was invalid.

	Mean	Std. Deviation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1- Gender	1.2381	0.43644	1														
2- Experience	1.7619	0.43644	0.05	1													
3- Area_design	2	0.70711	0.324	0.162	1												
4- Complete_task	1.7143	0.64365	-0.102	0.102	0	1											
5- Potential_of_outdoor_use	3.9048	0.94365	-0.064	-0.422	0.075	0.282	1										
6- Interaction	3.8571	0.85356	-0.038	-0.499	0	0.013	0.603	1									
7- Multi_user_potential	4.3333	0.65828	-0.116	-0.058	0.107	0.236	0.376	0.356	1								
8- Brightness_and_contrast	4.2381	0.70034	0.296	-0.132	0.202	-0.063	0.036	0.311	0.145	1							
9- Resolution	4.1429	0.91026	0.162	-0.162	0.155	-0.012	0.249	0.542	0.25	0.807	1						
10- Field_of_view	3.8095	0.87287	-0.269	0.006	-0.243	0.343	0.159	0.364	0.116	0.405	0.539	1					
11- Eye_strain	3.8095	1.07792	-0.111	0.005	0.197	0.062	0.325	0.458	0.305	0.46	0.641	0.597	1				
12- Environment_tracking	3.1905	0.87287	-0.256	-0.531	0.162	0.013	0.387	0.508	0.58	0.004	0.027	0.05	0.2	1			
13- User_movement_tracing	3.4762	0.87287	-0.313	-0.344	0	0.343	0.301	0.364	0.232	0.051	0.099	0.519	0.526	0.531	1		
14- User_interface	4	0.83666	-0.137	-0.548	-0.254	0.186	0.443	0.63	0.454	0.341	0.394	0.411	0.388	0.411	0.548	1	
15- User_friendliness	4.1429	0.57321	-0.143	-0.657	-0.123	-0.019	0.396	0.657	0.398	0.409	0.438	0.357	0.451	0.642	0.657	0.834	1

Figure 7. Experiment 1: Descriptive Statistics

From the descriptive statistics of Experiment 2 (Figure 8), correlations among elements occurred more than in Experiment 1's. The two tracks, 'environment tracking' and 'user movement tracking', have the highest correlation rate, 0.981, which is unsurprising. As the user moves in physical space, an update on the digital environment captured by the mobile camera which provides a more accurate representation of the woven model to be explored parametrically. 'Brightness and contrast' revealed its high correlation with the other five elements, suggesting that the commercially available mobile application used in Experiment 2 has a positive impact on the 'field of view', 'colour', 'eye strain', 'environment tracking' and 'user movement tracking'. These might show that the brightness and contrast of the digital model provide fundamental footings on delivering a usable AR model. The other pertinent element is 'interaction', which has a considerably high correlation with 'multi-user potential' and 'resolution'. Next, potentials and challenges are discussed, as mentioned by 21 participants who participated in both experiments.

	Mean	Std. Deviation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1- Gender	1.2381	0.43644	1															
2- Experience	1.7619	0.43644	0.05	1														
3- Area_design	2	0.70711	0.324	0.162	1													
4- Complete_task	1.8095	0.67964	0.161	-0.161	0	1												
5- Potential_of_outdoor_use	3.9524	1.11697	0.127	-0.127	0.127	0.449	1											
6- Interaction	4.0952	1.09109	0.16	-0.055	0.13	0.363	0.578	1										
7- Multi_user_potential	4.1905	0.92839	0.129	-0.129	0.076	0.14	0.684	0.82	1									
8- Brightness_and_contrast	4.1905	0.81358	0.007	-0.007	0	-0.022	0.451	0.542	0.678	1								
9- Resolution	4.1905	0.7496	0.007	-0.16	-0.283	-0.023	0.37	0.649	0.592	0.429	1							
10- Field_of_view	3.8095	0.98077	-0.122	-0.228	-0.144	0.018	0.493	0.392	0.426	0.674	0.596	1						
11- Colour	3.7143	1.30931	0.125	-0.125	-0.162	-0.008	0.537	0.65	0.623	0.664	0.721	0.578	1					
12- Eye_strain	4.0476	0.97346	-0.146	0.028	0	0.0140	0.692	0.56	0.598	0.619	0.604	0.796	0.639	1				
13- Environment_tracking	3.5238	1.12335	0.243	-0.345	0.252	-0.0590	0.419	0.488	0.571	0.651	0.351	0.73	0.447	0.525	1			
14- User_movement_tracing	3.5714	1.07571	0.228	-0.335	0.263	-0.049	0.44	0.505	0.586	0.669	0.354	0.724	0.477	0.546	0.981	1		
15- User_interface	3.8571	1.10841	0.177	-0.281	0	0.427	0.721	0.839	0.854	0.586	0.636	0.526	0.625	0.609	0.545	0.533	1	
16- User_friendliness	4.0952	0.83095	0.21	-0.348	0	0.2990	0.598	0.817	0.883	0.637	0.612	0.453	0.67	0.489	0.587	0.607	0.884	1

Figure 8. Experiment 2: Descriptive Statistics

Through 42 sessions (21 participants did two experiments each), two open-ended questions were asked to gain more in-depth insights. Firstly, regarding Experiment 1's advantages, 95% of participants (except Participant 2, P2, henceforth) would recommend the ball-making exercise to others; this shows positive acceptance of the use of AR in novice or aspiring bamboo artisans. Observed advantages by participants include: 1) being able to see all sides (360-degree views) of the object, as mentioned by P1, 2) step-by-step assembly guide, as stated explicitly by six participants (P7, P11, P16, P18, P19 and P21), and 3) learning the basic process of weaving bamboo, as posited by P13 and P14. Although the ball making exercise does not exemplify a typical interlocking bamboo weaving exercise, the researchers also observed that it would be better to start with a traditional weaving pattern exercise, for instance, the Indonesian traditional woven pattern "sasag" as shape grammar studied by Harnomo and Indraprastha (2016). Potential developments mentioned by the participants include: 1) possible use beyond bamboo artisans but also for sculptors and craftspeople as stated by P21, and 2) exploring (full-culm) bamboo joints.

In terms of Experiment 1's disadvantages, P2, who was against recommending the interface, provided valuable insights. He mentioned that the use of an AR interface would be useful for beginner bamboo artisans; however, for a more complex structure, further modification is needed. This increased complexity for Experiment 1 will also increase the file size of the application to be deployed in the mobile device, which might turn into experiencing lag. Another suggestion is to provide animated instructions within the AR interface. The researchers also observed that the colour-coded assembly system did not work well, especially when the interface was deployed in a bright environment. Further improvements on Experiment 1 were suggested, such as 1) a written guide, as suggested by P6; 2) simplification, perhaps in the form of animated instructions; and 3) a more developed assembly system comprising more than simply colour coding. Similarly to Experiment 1, 95% of participants would recommend Experiment 2 to others, except P2. Regarding Experiment 2's advantages, univocally, the reported benefit is related to the ability to visualise design options in real-time by changing design parameters; see examples in Figure 3. Design options include shape, position and size, as observed by P16; although from Figure 4, from the comparative rating between Experiment 1 and Experiment 2, in general participants preferred the experience they received in Experiment 2. However, from the open-ended questions, other positive aspects of Experiment 2 were sparsely explained. Through the data collection process, the researchers observed that the use of Experiment 2 or a similar interface is more suitable for earlier design phases where different forms and dimensions are generated, design situations in which flexibility of exact dimensions is acceptable. P15 posited that simulating design options would be useful before physically making the design.

Figure 9. Experiment 1: Final product (left) and final AR step (right)

Experiment 2's disadvantages are highly related to the fact that the interface only simulates the 3D model or design options without the assembly steps. Dimension is also another factor mentioned by participants (P4 and P18), which might suggest that one of the design parameters to be simulated is the width of bamboo strips, perhaps along with an overall dimension to give a more accurate representation of the simulation. Further developments related to Experiment 2 include 1) combining with Experiment 1 assembly process (P2 and P13), 2) providing a more accurate dimension, and 3) improving the surface detector as the hologram tends to float in space. This can be improved by including a marker, such as the printed paper in Experiment 1.

Overall, Experiment 1 and Experiment 2 present a positive utilisation of technology for design and construction, which was tested in small-scale bamboo woven explorative objects in this study. The two experiments were positively appreciated by 21 participants with design disciplines background (architecture, interior design, and industrial design). It was observed that incorporating AR could also be a way to promote traditional bamboo woven patterns in any applicable country with potential educational or informational tools to aid keen bamboo woven enthusiasts who do not have access to learn from expert weavers. The utilisation of this technology in a mobile environment can be seen as an effective designing tool as it is without any additional investment due to the proliferation of mobile devices. In a follow-up interview, P2, who was the only participant who was not in favour of the two experiments, mentioned that he did not see the AR interfaces used in this study as more beneficial compared to using video instruction. This presents a strong argument in terms of how the AR interfaces should be able to be intuitively used with strong additional benefits compared to a video tutorial with a minimal learning curve. From the listed AR advantages in the related literature section, this study explores the possibility of combining an 'assembly guidance system' with bamboo woven craftsmanship.

Conclusion

This study was conceived through the researchers' personal experience of learning how to weave using bamboo strips without expert guidance. The main difference between Experiment 1 and 2 is the nature of assembly. In Experiment 1, a step-by-step of assembly of six bamboo strips was simulated for novice designers to follow the instructions to make a ball. In Experiment 2, a basic parametric design object was simulated, allowing designers to view different options in real-time by tweaking the parameters. In both experiments, a positive experience is highly related to user-friendliness and user interface, as suggested by the descriptive analysis. In Experiment 1 however, user-friendliness is more dominant compared to its user interface. In contrast, Experiment 2 is the reverse; the user interface is highly related to visual AR components and a smoother interface display because it is a commercially developed mobile application. To reiterate the research question, *"What are the potentials and challenges of using mobile AR in the bamboo woven design process?"* The observed potentials include being able to see 360-degree views of the object assembly guide, being able to learn the basic process of weaving bamboo strips and the ability to simulate ideas rapidly. The main challenges which surfaced through this study were accuracy (dimension), hologram colour being suitable for indoor and outdoor use, and challenged benefits in comparison with pre-recorded video tutorials. Further recommendations from these observed challenges which can be implemented as future applications of the research include suggesting a more developed assembly system, combining the two experiments' set-up (assembly guide and parametric design features), including written guides and animated instructions, achieving more accurate dimensions and improving the surface detector with markers (for Experiment 2).

The limitations of this study involve the small number of participants; the ad-hoc jointing system during experiments using tape due to the presented two designs, which need to be avoided; and the inability to use real bamboo strips due to the thickness. The available 0.1mm and 0.2mm thickness bamboo strips were too thick for small three-dimensional objects. Future studies include promoting and cataloguing traditional two-dimensional patterns through the use of AR and an improved interface which can combine assembly and rapid design iteration.

Conflict of interest

The authors declare there is no conflict of interest

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