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Research Article

ARKitchen: Kitchen Design with Tangible Augmented Reality Using Magnetic Markers and Iron Workspace

Meng Chun Lam [1*], Nur Afyfah Suwadi [2,3], Siok Yee Tan [2], Haslina Arshad [2]

[1] *Mixed Reality and Pervasive Computing Lab, Center for Artificial Intelligence Technology, Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia. Email: lammc@ukm.edu.my*

[2] *Mixed Reality and Pervasive Computing Lab, Center for Artificial Intelligence Technology, Faculty of Information Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia*

[3] *School of Computing and Creative Media, University of Technology Sarawak, 96000 Sibu, Sarawak, Malaysia*

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ABSTRACT

Modern kitchen cabinets play an important role by offering more than just storage. They are designed to improve convenience, efficiency, and sustainability in the kitchen. While designers have a clear vision of the kitchen layout, customers may find it harder to visualize. However, the customer may find it challenging to fully comprehend how the design will manifest in reality. Augmented reality helps users visualize kitchen designs in 3D, making users perceive the design more effectively. This study proposed and evaluated an application named "ARKitchen" that uses augmented reality technology to visualize the kitchen in 3D. The application offers manipulation features such as placing, relocating, and deleting kitchen cabinets, as well as adjusting their characteristics. Additionally, it utilizes a physical workspace and magnetic cards as tangible mediums to facilitate intuitive interaction. Each magnetic card represents a different size and type of kitchen cabinet. Users place the cards on an iron workspace to arrange their ideal cabinet layout. The application has been evaluated by 25 users from the end user's perception of quality attributes (QA), cognitive attributes (CA), and attitude towards using (ATU). Overall, users gave positive feedback on ARKitchen. The results show that quality (QA) scored 4.09, cognitive ease (CA) 4.06, and user satisfaction (ATU) 4.49. Users found the app useful, reliable, and easy to use (QA), with low mental effort (CA). They were satisfied and would like to use it for kitchen design (ATU).

Keywords: Augmented reality, kitchen design, mobile AR, tangible augmented reality.

INTRODUCTION

The presence of Augmented Reality (AR) technology has opened numerous possibilities for inventive, interactive, captivating, and embodied visualization [1]. AR seamlessly combines real-world surroundings with computer-generated virtual objects, enhancing the user's perception of reality [2; 3]. The creation and adoption of AR in design were influenced by the advancement of modern technology and computer graphics [4]. In the past, AR technology was limited by expensive hardware and often produced low-quality results. However, with advancements in technology, AR has become increasingly accessible through smartphone or tablet devices.

Nowadays, individuals value interior design goods and love creating their own spaces. Unfortunately, they are unable to assess every item of furniture in their houses due to time, resources, accessibility constraints, which makes the experience of interior design challenging overall [5]. Customers often wonder how a particular furniture piece will fit into their room before making a purchase, but imagining the outcome can be difficult. Meanwhile, kitchen design typically involves hiring experts like interior designers to understand the homeowner's preferences and create visualizations based on discussions and measurements. This process often requires multiple revisions before finalizing the design and producing technical drawings for construction. As a result, designing a custom kitchen can be time-consuming, leading to project delays and exceeding budgets. Miscommunication between homeowners and

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designers can lead to frustration, especially when the final result does not align with the homeowner's vision [2]. AR seamlessly blends the real world with a digital interface in real-time, utilizing 3D registration and tracking technology to integrate virtual items into the physical environment [6; 7]. Utilizing AR for kitchen design has the potential to diminish misunderstandings and enhance user perception [8]. AR improves the kitchen design process by seamlessly integrating digitally crafted 3D kitchen cabinet models into physical spaces, mirroring the envisioned outcome of the kitchen design [9; 10]. Furthermore, the tangible AR approach that links virtual objects to physical medium allows users to interact with virtual elements in an intuitive and engaging manner [11]. Tangible AR could empower designers to manipulate physical objects for direct interaction with and modification of kitchen designs in real-time, resulting in a design experience that is more intuitive and cohesive compared to traditional 2D interfaces. Tangible AR enables the manipulation of 3D kitchen models, including properties such as width, color, and handles, thereby presenting users with a new way to design the kitchen.

In this paper, we explore the use of AR technology for supporting the design of the kitchen cabinet, utilizing a tangible user interface aimed to provide a better experience to user. Unlike traditional methods like hand sketching or kitchen design software, ARKitchen runs on smartphones or tablets along with a tangible user interface. The tangible user interface comprises a set of magnetic AR markers and a design board, facilitating effortless attachment of the markers onto the board by the user. ARKitchen could benefit kitchen design companies by boosting sales. It also could serve as a training tool for new designers and students studying engineering subjects like product design. The paper is organized as follows: Section 2 reviews related works on AR in design and tangible AR. Section 3 outlines the process and methodology of ARKitchen, followed by a tangible architecture in section 4. Section 5 discusses the evaluation, section 6 explains the result, and finally, the paper concludes.

RELATED WORKS

Numerous studies and prototypes in AR have been developed to expedite the design process and empower users to generate interior design concepts independently [2; 12]. Approaching the subject from different angles, a research team delved into the utilization of AR for renovation planning [13; 14], while another focused on its AR application for viewing architecture and construction projects [15]. Additionally, certain authors investigated the nuances of mobile AR for interior design applications [16; 17]. Advancements in AR technology have also enabled users to superimpose virtual furniture onto their existing pieces, facilitating furnishing without the need to purchase or physically move items [16; 18]. Furthermore, a study has been conducted to pinpoint the physical space location for arranging furniture using markerless AR with simultaneous localization and mapping (SLAM) algorithm [19]. Additionally, AR Furniture has been introduced, offering real-time visualization of furniture in different colors and styles [20].

AR interaction can be multimodal, incorporating gaze, gesture, tangible, and voice commands to create a natural and engaging user interface [21]. The interaction in AR can be significantly enhanced through tangible AR interfaces, which connect the 3D virtual objects and physical medium at a certain level. Additionally, tangible AR authoring tools, like the immersive authoring, facilitate the creation of AR applications within the AR environment, enhancing the design and development process [22]. Tangible AR has the potential to enhance the learning processes. [23] and [24] both emphasize its potential in architectural design learning, with the former proposing a theoretical framework and the latter discussing its application in architectural design education. Meanwhile, [25] and [26] highlights using physical marker cards to control the color, material, and placement of virtual furniture and decor items. This allows users to experiment with different design options interactively. It brings an intuitive, hands-on approach to visualizing and iterating on design concepts. In this study, we have developed an AR mobile application named ARKitchen. It offers customers AR experience using tangible AR, allowing them to interact with virtual objects through physical medium. Unlike traditional methods where users manually select cabinet options from catalogs and position them using a mouse and keyboard. ARKitchen simplifies the process by enabling direct interaction with virtual objects. Besides, users can easily position the kitchen design, store design details, and manage them in a web portal with just a few simple steps.

METHODOLOGY

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In this study, we interviewed kitchen designers from different companies to understand kitchen design concepts and procedures. A semi structured interview has been adopted, and the designers elaborated their answers based on their views and experiences. We also showed the prototype of the tangible AR kitchen application [26], aiming to elaborate the AR technology and gather feedback on the existing prototype to enhance both its variety and functionality. Based on the interviews, the design flow is depicted as shown in Appendix A. The designer also provided insights into which elements should be incorporated into the AR application to assist users in finalizing their kitchen designs. Based on the valuable feedback of kitchen designers, the researcher further improved the prototype and developed a new AR application called ARKitchen. Following the completion of development, a user evaluation was conducted to assess ARKitchen.

This research has developed a mobile AR application named "ARKitchen," which uses AR technology to assist customers in visualizing furniture pieces in a kitchen platform. The ARKitchen, the primary physical elements comprise the AR magnetic marker and the iron-based physical workspace, alongside a mobile AR application and a web portal for project management. It allows users to: 1) interact with magnetic AR markers to create detailed arrangements of kitchen cabinet and appliance positions, 2) see the 3D models of the kitchen and appliances, 3) change the properties of the kitchen cabinet (door handle design, tabletop, and door material), and 4) manage the kitchen design project via a web portal. The app also provides product information such as material and price estimates to aid decision-making.

Physical workspace

The physical workspace comprised iron, facilitating the marker's adherence (Figure). Additionally, it offers guidelines indicating the size of the kitchen cabinet or kitchen space, with one small box equating to a 10 mm representing 0.4 ft in real cabinet size.

Physical Magnetic Marker

The physical medium used in this kitchen design is a physical marker which is made from magnetic card material. A total of 59 cards have been developed which consist of different types of doors, drawers, fridge, sink, hood, stove, and dishrack. The design of each marker is unique in terms of the pattern (Figure). The open-source hash code generator has been used to create a different pattern of the square dots. Then, the design was created using Adobe Photoshop and printed onto magnetic material so that it can adhere to the physical workspace. The magnetic marker also followed the measurement ratio. For example, 1 door with a width of 2 feet was represented by a 50 mm wide marker.

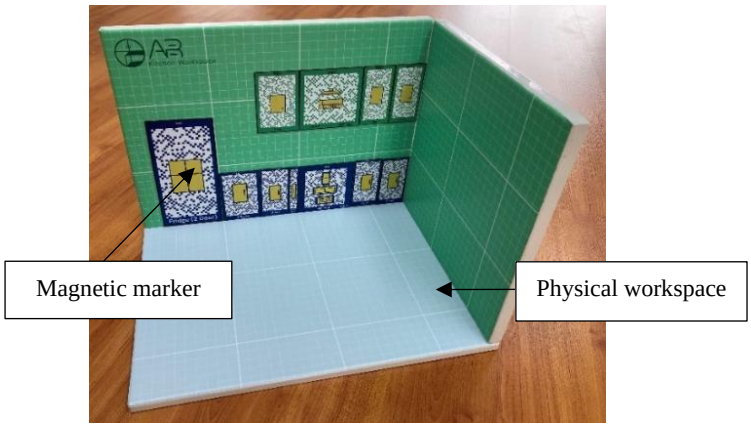

Figure 1. Physical workspace of ARKitchen

Marker Details

The marker includes a variety of door types and kitchen appliances. To differentiate between base and wall markers, this study used different colors. Blue for base markers and green for wall markers. For the base kitchen marker, doors come in sizes of 1.5 feet and 2 feet for single doors, and 2.5 feet for double doors. Drawers are available in sizes of 1.5 feet and 2 feet. Base kitchen appliances include sinks (single at 2.5 feet and double at 3 feet and 4 feet), stoves (3

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feet), fridges (2.5 feet, 3 feet, and 3.5 feet), and tall oven (2 feet). The stove shares the same marker with the 3 feet double sink. For wall kitchen markers, doors are 1 foot and 1.5 feet. Wall kitchen appliances include hoods (2 feet, 2.5 feet, and 3 feet) and dish racks (2 feet, 2.5 feet, and 3 feet). The hood shares the marker with the dish rack for all sizes. Appendix B illustrates the variety of marker types and sizes for ARKitchen.

Physical Magnetic Marker

The mobile AR application itself allowed users to change the arrangement of the marker physically. To visualize the 3D kitchen, users need to affix the marker onto the physical board in their desired position and can remove unwanted designs from the workspace. Each marker is assigned a unique ID along with a brief description of the corresponding kitchen cabinet and appliance (e.g., 2 doors, 3 doors, sink, etc.). The application can recognize the marker and display the corresponding 3D model. Users can alter the kitchen color, texture, and handle by utilizing the menu within the app. Subsequently, the properties of the kitchen cabinet will change according to the user's selections (Figure).

Figure 2. ARKitchen 3D model mobile application

Management Portal

The application incorporated a web portal management tailored for business purposes, enabling the system to generate, modify, display details of, and delete subscription plans within the platform. It can oversee kitchen design company particulars like company name, registration information, subscription duration, etc. The web portal was able to store the user data and allowed the mobile app to upload the kitchen designs. More importantly, the web portal permitted administrators to search and review stored kitchen design projects, inclusive of kitchen layouts, material specifications, and pricing information.

EVALUATION

Participant

The ARKitchen was evaluated by a total of 25 participants. Eight of them are male and seventeen are female. In addition, 12 of the participants are in the age range 20-29, 11 of the participants are in the age range of 30-39 and 2 of the participants are in the age range 40-49. Participants come from diverse educational levels, including A-level, bachelor's degree, and postgraduate students. The participants' backgrounds include kitchen design, science, engineering, accounting, and marketing.

Task

To evaluate the ARKitchen, we established tasks for users to complete uniformly. These tasks include logging in, starting a design, arranging kitchen cabinets and appliances in the AR workspace, changing their positions and materials, taking screenshots, and after that enter the details to save the project. The designed task aims to assess the ARKitchen's usability and gather user feedback for the enhancement.

Evaluation Process

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At the beginning, participants were asked to fill in the consent form and provide their background information. The evaluation starts with a tutorial that shows participants how to use the application's various features. Then, participants were allocated 10-15 minutes to familiarize themselves with the application. Afterward, the participants are asked to perform the tasks. After that, the participants are asked to answer the questionnaire about the quality attributes, cognitive attributes and attitude towards using which adapt from [27] and open-ended questions to gather the positive and negative aspects of the application and the improvement that should be made.

RESULT AND DISCUSSION

The familiarity level of AR Apps

The familiarity questionnaire consists of three questions with 5-points Likert scale. In the first section, familiarity, the participants were asked about familiarity with AR, familiarity with AR applications specific for design usage and their frequency of use of AR technology. Based on the familiarity question, only 4 out of 25 participants identified as strongly familiar with the AR application, with an equal number reporting that they are familiar with it. When specific for the design usage, most of the participants, or 13 participants, were not familiar with the AR application in design. One participant cited prior experience with the IKEA app as their reason for selecting the "strongly familiar" option. Furthermore, for the uses of AR technology in users' daily life. Most of the participants only used it sometimes as they experienced it with another type of AR application such as AR for the car show, Pokémon Go games, and kid's AR card application. Meanwhile, 4 participants never used an AR app before, then 8 participants rarely used the AR app, 1 participant very often used it, and lastly, 2 participants always used the AR apps in their daily life. In summary, all of them have less experience with AR technology.

Quality of application

This section outlines the evaluation question we conducted to assess the effectiveness of ARKitchen application based on end users' perceptions of quality attributes (QA), cognitive attributes (CA), and attitude towards using (ATU) [27]. QA focuses on reliability, accuracy, and user-centric challenges, while CA relates to mental processes like attention and decision-making. ATU refers to the collection of characteristics that result from the perceived usefulness and ease of use. Participants rated their agreement with these attributes using a 5-point Likert scale.

Questionnaire results

Overall, the mean scores are above 4.00, except for one question from QA and CA attribute respectively (see Appendix C). For the QA questions, participants found the app to be user-friendly and reliable for kitchen design. They appreciated the visual appearance in 3D, which aligned with their expectations for a kitchen design mobile app. However, some participants suggested improvements were required for this app, particularly in the variety of kitchen cabinet designs, marker stability, and portability of the physical workspace. Participants also felt the app accurately assisted in kitchen design, boosting confidence and easing the process, as in the CA question. In terms of feeling in control while using the app, some participants struggled due to their limited AR knowledge and the abundance of AR markers, which slowed down the selection or decision-making process. For the ATU questions parts, the majority of users agreed that the app was easy to use and beneficial. They enjoyed using it and would recommend it to others for its design assistance.

Discussion based on subjective feedback and observations

The evaluation showed that most participants agreed on the usefulness and ease of use to start the kitchen design. For further improvement of the application, participants were asked several open-ended questions. The answers, along with summaries, are discussed below.

Users highlighted the positive aspects of this application, noting its flexibility in design, which enhances its efficiency of use. Besides, it is easy to use, and users like it because it is mobile and can be brought anywhere, interactive, has several options available for design, and is user friendly. The next element from the user comment is about aesthetics and design. This app offers excellent visualization, and a variety of kitchen design options that match with various themes of a house. Users appreciate its creative approach to arranging designs, realistic depiction, kitchen space ratios, modernity, intuitiveness, adherence to trends, and realism. Another participant comment highlights how this

app can be beneficial to users. It aids in making informed decisions, saves time and energy, allows users to see the direct results of their kitchen design, enables accurate price estimation, assists in the kitchen design training phase, and simplifies the process of kitchen designing. The next positive aspect involves user control and freedom. This application offers users freedom in both space and time, allowing cabinets to resemble customers' demands, fostering creativity, exhibiting significant potential, and being highly customizable. And lastly, users feel enjoyment while using the app.

Limitations and future improvements

The feedback from participants highlighted some issues with this application, including problems with marker tracking and occasional slow response times, which reduced the stability of the 3D kitchen visualization. These issues are worsened when the camera is pointed at a sharp angle toward the marker or in poor lighting conditions, whether it is too dim or too bright. Furthermore, participants noted that the AR marker system was inflexible and not very user-friendly. Users have to carry the marker with them every time they use the ARKitchen, managing over 50 different markers can be cumbersome and the heavy weight of the iron workspace. Besides, the AR markers need to be positioned correctly. Otherwise, the alignment of the 3D kitchen visualization on the app will not be accurate. Therefore, a different mechanism is required to assist the user in automatically aligning the AR marker or 3D kitchen cabinet in the future. Regarding 3D models, kitchen designers noted a lack of options for kitchen cabinets, limited design choices, and the quality of realism affecting user satisfaction. Even though regular users or clients were satisfied with the quantity and visual quality of the 3D models. Users also expressed a desire for more layout options and support for larger kitchen spaces. They felt restricted by the app's limited workspace, noting the absence of island and U-shaped kitchen configurations. They also suggest expanding item variety, adding more cabinet or appliance options, providing detailed information, exploring additional rooms, and considering markerless AR or VR technology for implementing real-scale visualization.

CONCLUSION

This study implemented AR technology to assist kitchen designers in tackling issues related to miscommunication during the kitchen design process. The primary outcome of the study was the creation of the ARKitchen app, which showed virtual 3D kitchen models seamlessly integrated into the real world and investigated the use of AR in kitchen design. The ARKitchen app offered functionalities like cabinet placement, relocation, deletion, and adjustment of characteristics, all utilizing augmented reality technology to visualize kitchens in 3D. It shows significant potential over traditional methods by providing flexibility to manipulate designs and instantly view the outcomes in 3D form. In the evaluation phase, users perceive the app as useful and reliable for kitchen design, experiencing low mental workload and expressing satisfaction with the app, indicating a willingness to use it for kitchen design purposes.

There are a few enhancements that could increase the feasibility of ARKitchen for kitchen designers. Many existing mobile applications offer real-time and precise space measurement capabilities, underscoring the importance of this feature for the kitchen design application. It would assist the client in determining the dimensions of their available kitchen space. Furthermore, it should ideally include a wide range of features, such as a greater variety of furniture and kitchen accessories, along with aesthetic refinements like wall, floor, and window designs within the kitchen area. It also would be beneficial to visualize the locations of electrical wiring and water pipes to help kitchen designers avoid placing screws in those areas. Besides, lighting visualization plays an important role, as some kitchen cabinets include LED light installations. Additionally, there is interest in expanding the app’s capability to incorporate advanced technologies like markerless AR or VR for unrestricted environmental design visualization. Last but not least, a template or suggestions for different kitchen layouts (I-Shape, L-Shape, U-Shape) based on the measured kitchen space can be included to assist new kitchen cabinet clients who lack ideas. These enhancements aim to make ARKitchen design apps more comprehensive, user-friendly, and effective in assisting users with their kitchen design projects.

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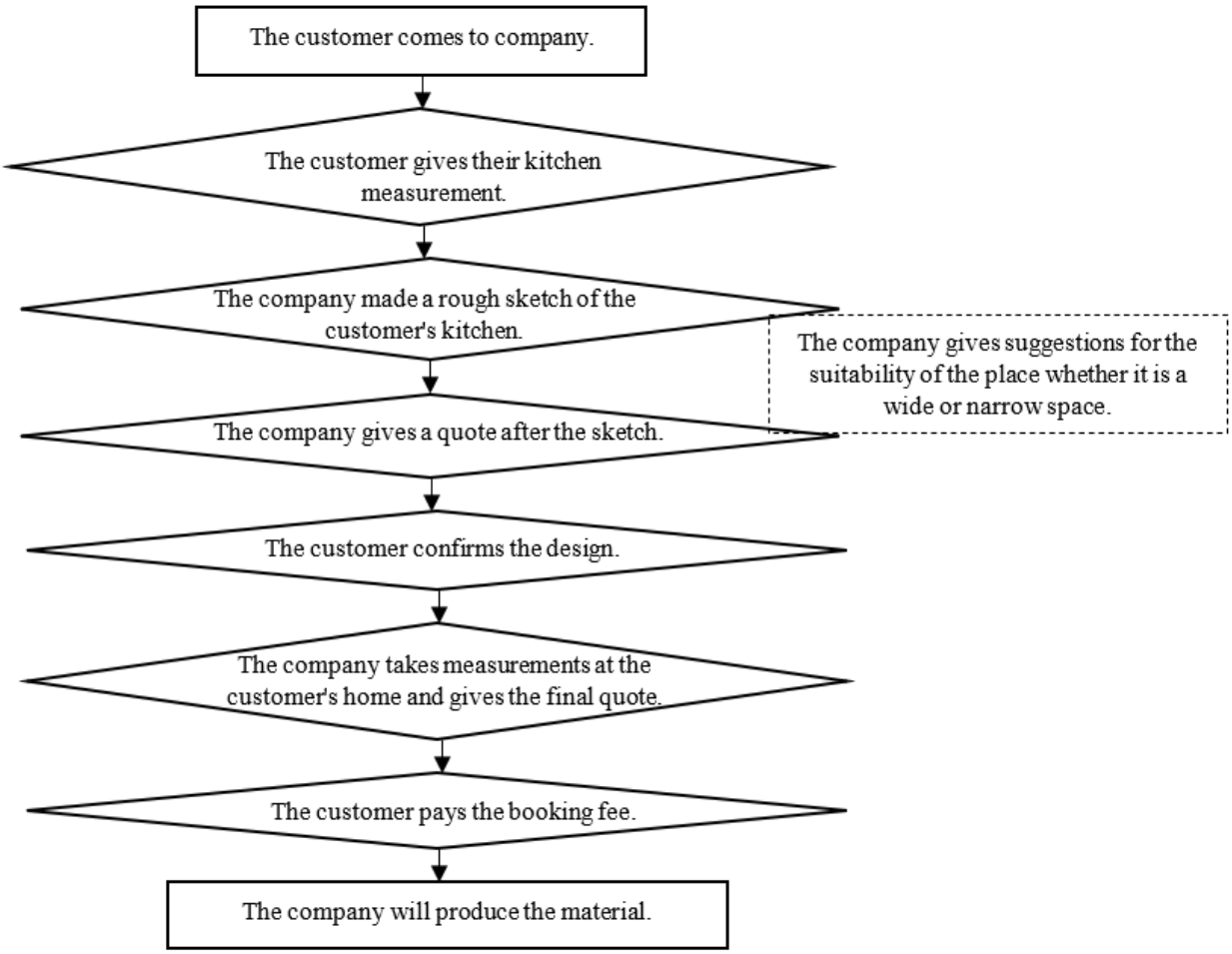
Appendix



Kitchen cabinet design and order procedure flow chart

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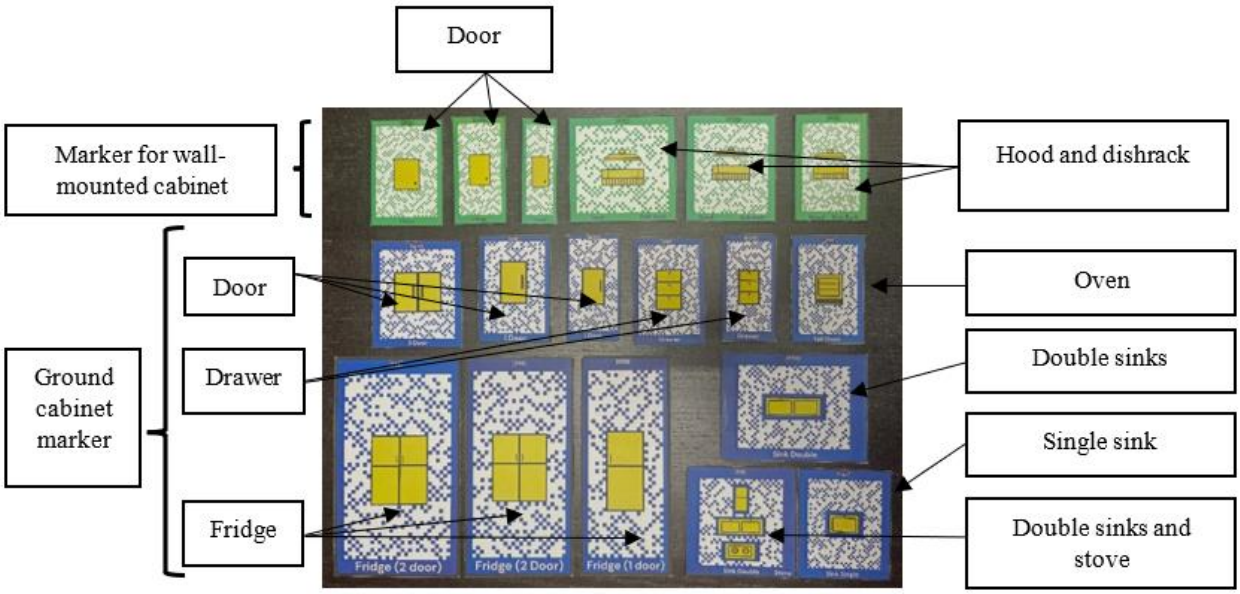

Marker types of ARKitchen. Color code used to differentiate the cabinet: green for wall cabinets, blue for ground cabinets. Marker sizes follow a ratio to represent their real-life dimensions. For example, a 1-door (2 feet) marker comes with a 50mm wide marker.

Table 1: Quality of Evaluation

	No.	Question	Mean	Std. Dev
Quality Attributes (QA)	1.	I found this application is user-friendly.	4.40	0.65
	2.	I felt that using this application was reliable in assisting me to make a kitchen design.	4.40	0.71
	3.	I felt that this application needs a lot of improvement (reversed item).	3.40	0.91
	4.	I liked this application visual appearance.	4.32	0.70
	5.	This application did not match my expectations (reversed item).	4.00	0.82
	6.	I felt that using this application was accurate in assisting me to make a kitchen design.	4.00	0.87
		Overall mean of QA	*4.09*	*0.77*
Cognitive Attributes (CA)	7.	I found this application confusing to use (reversed item).	4.36	0.57
	8.	I got flustered when using this application (reversed item).	4.16	0.69
	9.	I felt in control throughout when using this application.	3.24	1.13
	10.	I felt under stress while using this application (reversed item).	4.48	0.65
		Overall mean of CA	*4.06*	*0.76*
Attitude Towards	11.	I will be happy to use this application again.	4.52	0.59
	12.	I enjoyed using this application.	4.52	0.59
	13.	I will recommend others to use this application.	4.48	0.71

Using (ATU)	14.	I will frequently use this application in the future if I have the chance.	4.40	0.76
	15.	I will say positive things about this application to future users.	4.52	0.65
		Overall mean of ATU	*4.49*	*0.66*

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