ENHANCING USER-ENGAGEMENT IN THE DESIGN PROCESS THROUGH AUGMENTED REALITY APPLICATIONS

Conducting an experiment to measure effectiveness of mobile augmented reality user interfaces

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Abstract. This research explores how to improve the opportunities for augmented reality technologies as a design communication tool, through developing criteria to test user interface and user experience in an interior design context. The process involves the development of three conceptual user interfaces created using Adobe Experience Design CC (Beta) 2017, and a simulated experience through the InvisionApp platform. The software was chosen on the basis that they are quick prototyping tools to adhere to time constraints. By testing prototypes against a series of customised heuristics, this research can reflect on ways to design MAR interfaces for use in the design industry. Heuristics refers to an existing technique of evaluating application effectiveness following a set criteria. Due to the general nature of heuristics, it is important to define a set that is unique to the project objectives (Nielsen, 1994). By designing and testing the user interfaces with 15 participants from PTW Architects targeting the appropriate demographic, this study outlines strategies of effective mobile augmented reality user interface design, and explores methods of measuring application effectiveness. The experiment uses inspection methods to better understand how to apply heuristic evaluation with appropriate consideration of the iterative design process.

Keywords. User Interface; Human-Centered-Design; User Experience; Heuristics; Inspection Method.

1. Introduction: Research Motivations

Within a single day users encounter a wide variety of digital interfaces. It is important that these interfaces are true to their intention and are easy to navigate, this is critical to their continued usability. Architectural practices often adopt digital technologies as tools for communicating design ideas. These practices have adopted digital applications as a means of showcasing design iterations to clients. This can enhance the communication between the designer and client during the iterative design process. Existing methods of presenting design iterations, can include 2 dimensional (2D) drawings and 3 dimensional (3D) renders or visualisations, however, static imagery is limited as it lacks the ability for real-time customisation. The communication between the designer and client can then prove troublesome when design intent is not mutually understood. While augmented reality (AR) technologies are a currently seductive option for enhancing the design communication between a designer and client, the significance of the design of the user interface (UI) and user experience (UX) are a little misunderstood from a designer's perspective. This project adopts methodologies such as inspection methods, which involves the use of a customised heuristic set to test the effectiveness of MAR UI applications. Effectiveness is defined as “the accuracy and completeness with which specified users can achieve specified goals in particular environments” (Stone et al, 2005). Within this research, these concepts will be explored and evaluated for future development of MAR UI and UX applications.

This project is in collaboration with PTW Architects and is a part of a larger project scope including Harris Paneras’ research paper ‘Augmented reality in the design process’ (2017) that explores quantification methods of motion tracking in augmented reality.

2. Research Aims

The aim of this research is to conceptualise and build various user interface layouts for visualising 3D objects in an interior design context with a project provided by PTW Architects. The UI and UX will then be tested and evaluated against project specific heuristics. The overarching expectation of this application is to enhance the design process, by streamlining the communication between the client and the designer.

With a focus on defining a process for developing and testing mobile augmented reality (MAR) user interfaces. This draws on key scholars who have explored existing UI evaluation techniques, and defined existing criteria sets; including Usability Heuristics (Nielsen, 1994) and Visual and Cognitive Heuristics (Zuk and Carpendale, 2006), a customised set of heuristics will then be developed to be specific to the project scenario.

Further tastings will then involve 15 participants who have design background knowledge, to complete tasks using two of the three proposed UI prototypes. The aim of the user testing is to inform the improvements to be made in prototype three and to compare the effectiveness of basing a UI purely on a customised set of heuristics or a process where users are involved in validating the UX.

3. Research Questions

Through a comparison study, research process and investigation into user needs, a MAR UI development process will be defined. The ultimate goal of achieving an effective UI is to engage the user into the design process. Therefore through an experiment, user testing will be evaluated to validate further improvement of MAR UI and UX prototypes. A criteria for an augmented reality mobile application for PTW Architects will then be established as a basis for MAR UI design. It justifies how the enhancement of MAR UX may refine the architectural iterative design process when communicating ideas with clients.

With the issues set out in the research introduction, this study poses the following questions:

1. How effective can the application of MAR tools be in an interior design context?
2. What criteria can be applied to test the effectiveness of a MAR user interface in an interior design context?
3. How effective is a project specific set of heuristics at the beginning of the development process vs after user testing?

4. Methodology

This research adopts an action research framework that is characterised by a mixed method approach that applies theoretical knowledge to test the design of three prototype interfaces (figure 1). Each prototype is influenced by various areas of the research methodology to consolidate the UI designs.

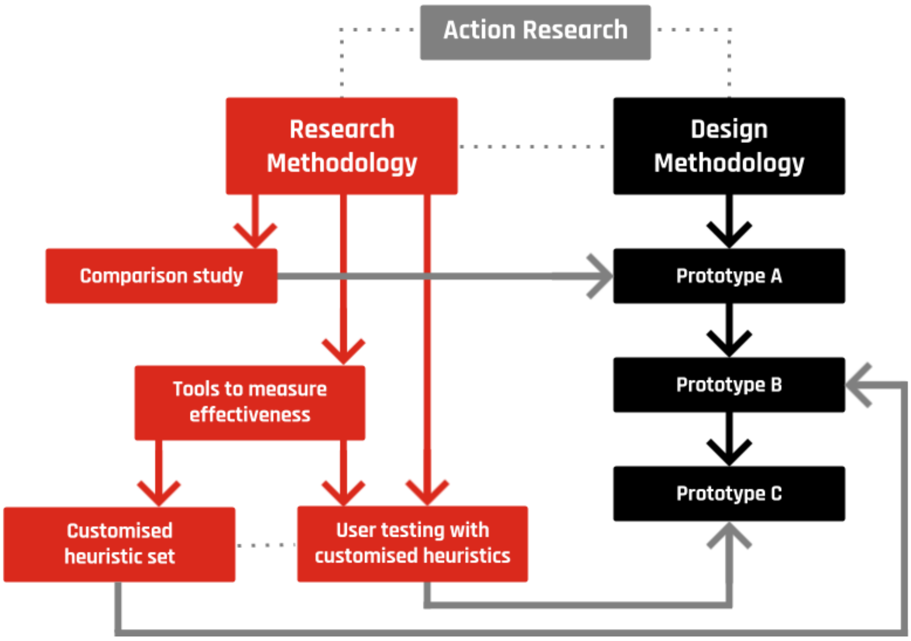

Figure 1. Research and design process.

The design project is divided into two areas; research methodology and design methodology, all of which fall under action research, with a focus on design research. Action research has a theoretical and a practical component that necessitates the evaluation of successive design iterations throughout the entire process. Similarly, design research involves addressing and proposing solutions for a perceived problem in the design field, to inform the direction of the design methodology to develop iterations and prototypes. The research into existing evaluation methods and their recommended uses, provide existing sets of heuristics commonly used for assessing interface design including, Usability Heuristics (Nielsen, 1994) and Visual and Cognitive Heuristics (Zuk and Carpendale, 2006). Heuristics are typically used by evaluators, although they will be applied as an inspection method for the purpose of evaluating prototypes with low experience users. The aim of this technique is to provide an "immediate validation approach" that can be applied to the iterative design process (Munzner, 2009). The heuristics, shape and inform the questions in the questionnaire of the experiment (appendix B, figure 21).

4.1 RESEARCH METHODOLOGY: THEORY

A critical review of existing literatures on key principles of UI design and existing evaluation techniques aim to inform what elements create an ‘effective’ MAR application, and further how it can be tested and compared (figure 2). From the review of an existing iterative design process as discussed by MacIsaac in 1996, this methodology has been defined: *Compare*, *Benchmark*, *Standardise* and *Quantify*.

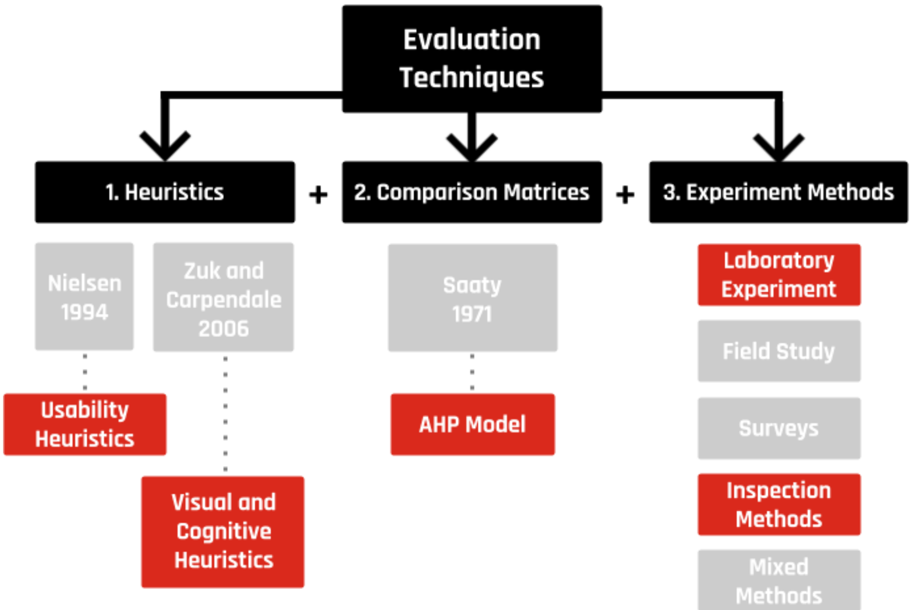

Figure 2. Existing evaluation techniques.

4.1.1 Compare: Comparison Study

Compare was driven by a technology review (appendix A, table 9) and comparison study of existing MAR, or similar, applications (table 3) to be measured against a customised set of heuristics (table 2). These included; Augment, Graphisoft BIMX, MagicPlan, Ikea Catalogue and Layar to highlight successes and limitations of their UI’s.
Many of the applications had the ability to place furniture in AR, creating a second layer in reality. Although these MAR applications lacked

customisation of materials on projected objects, restricting design solutions available.

4.1.2 Benchmark: Initial Measuring of Application Effectiveness

Benchmarking refers to methods of measuring the effectiveness of mobile applications. Existing sources provide performance indicators of MAR applications and outline a baseline for the iterative design process (Kourouthanassis' et al, 2013).

4.1.3 Standardise: Brand Specific

Standardise defines the use of industry specific requirements to structure application functionalities. For example, PTW Architect's design guide is applied as a standard of specific colours and fonts in the UI prototypes.

4.1.4 Quantify: Heuristics and AHP Model

Quantify describes heuristics – also known as a "criteria" – to test application usability, visual and cognitive functions (Santos, 2015). Heuristic evaluations use a criteria as a standard to examine application interface designs.

The heuristic can be formatted using the Analytic Hierarchy Process (AHP) model, to determine application usability and user satisfaction (Nielsen, 1994). The AHP model measures effectiveness using ratio scales to stray from subjective opinions. This model is applied to the iterative design process to select the best performing prototype.

Visual and cognitive heuristics also explore gestalt principles and layout design to define the most effective solutions for any given application (Zuk and Carpendale, 2006). Such techniques can enhance the attractiveness of the application while also improving ease of use, all of which add to its overall effectiveness.

4.1.5 Heuristics

It is difficult to establish an optimised heuristics set for a particular project (Nielsen, 1994). Nielsen's usability heuristics and Zuk and Carpendale's visual and cognitive heuristics provide a generalised approach to identify application limitations. As different heuristic sets may possibly overlap, it is important to prioritise which are most relevant to the project. To achieve this, a customised list is designed that combines key criteria from both sources that relate to the context of the project. These scholars have provided a basis for the design development process, as the revised list of heuristics are specific for use in MAR UI development.

4.2 DESIGN METHODOLOGY: PRAXIS

Following the process of *Compare*, *Benchmark*, *Standardise* and *Quantify,* a technology review and comparison study of existing MAR applications provides a selection of key principles and techniques that are successful in their UI and UX designs (appendix A).

4.2.1 Prototype A

To test the effects of these outlined principles, prototype A will have a simplified layout, when compared to prototype B, for navigation influenced directly by the technology review (appendix A) and comparison study of existing applications (table 3).

4.2.2 Prototype B

Prototype B will delve specifically into the customised heuristic set as the basis for design decisions (table 2). It will focus more on the usability performance as well as visual and cognitive aspects through a more advanced control panel.

4.2.3 Tools to measure effectiveness: The Experiment

To inform prototype C, an experiment measures prototype A and prototype B's usability and visual and cognitive performance, to lead to establishing what achieves an effective application. The following methods can be used to measure application 'effectiveness':

a. *Experiment:*
   Somewhat controlled conditions and consented observation.
b. *Field Study:*
   Involves observation often without consented observation.
c. *Surveys:*
   Questionnaires specifically designed for a group of participants.
d. *Inspection methods:*
   Heuristic evaluation is a style of inspection method to measure application performance.
e. *Mixed methods:*
   Combining multiple tools.

This study engages with a mixed methods approach by combining an experiment, surveys and heuristic evaluation as the inspection method.

4.2.4 Data collection methods

Figure 3. Data collection methods

From testing these prototypes, both quantitative and qualitative forms of data are gathered. *Quantitative* data is collected through a questionnaire after a participant experiences two prototypes on an iPad. The questionnaire is based on the AHP model and provides the user with rating system (appendix B, figure 21). Further data is to be gathered through video recording participants using the prototypes to document the number of taps and time taken to complete the set tasks. *Qualitative* data is further collected at the end of the questionnaire in written form to gather a selection of statements and a preferred prototype.

4.2.5 Prototype C

Prototype C will derive its key principles of UI and UX design from the key findings of the conducted experiment testing the effectiveness of prototype A and prototype B. The experiment along with the customised heuristic set will provide a foundation of effective and validated principles for the development of this iteration.

5. Background Research

5.1 USER INTERFACE AND USER EXPERIENNCE

Human-computer interaction (HCI) is the interaction between a user and a device through the means of a UI. The UI is the form of communication between a user and the application. A UI should therefore support self-efficacy, as the effectiveness of a UI can greatly impact the UX. The UX is enhanced through a more thought out UI that has engaged with a user-centered design approach as a part of the iterative design process.

5.2 USER-CENTRED DESIGN

User-centred design is the integration of users in the iterative design process. The process of plan, action, observe and reflect (MacIsaac, 1996) involve user engagement in the form of user-testing, interviews, surveys or any other inspection methods to develop iterations. Adopting such approaches will positively be reflected through effective usability of the final application (Stone et al, 2005).

5.3 COGNITIVE SCIENCE

An effective UX can be understood and evaluated by focusing on cognitive functions, as a way of engaging the user. Cognition is the way the mind processes tasks that involve memory, problem solving, thinking, perception, and creativity. In particular, user interfaces engage users with conscious and unconscious visual cues to support concept learning (Allport, 1960). An important relationship exists between the idea of concept learning and a user’s central memory. Working memory for example is used while operating an application, as users have the ability to remember three to five items, four being the optimal number (Cowan, 2010). In the case of an MAR interface, replacing text with icons can simplify the amount of content the user is able to remember. This suggests that icons are the most effective method for displaying menu items, as they are easier to recognise and memorise (Noh, 2014). User interface design typically applies techniques drawn from cognitive science to enhance layout design and functionality methods.

5.4 HEURISTIC EVALUATION

Usability, aesthetics and functions can be tested using historical quantification techniques (Santos et al, 2015). Heuristic evaluation is a method of examining an application based on a set criteria. Key scholars who examine heuristic evaluation methods include Nielsen's usability performance heuristics (1994) and Zuk and Carpendale’s visual and cognitive heuristics (2006). The heuristic principles of each area allow for testing a more comprehensive MAR application prior to conducting formal testing in a controlled experiment.

5.5 ANALYTIC HIERARCHY PROCESS MODEL

The AHP model methodology can be applied to the iterative design process (Meei Hao Hoo et al, 2013, Sharmistha Roy et al, 2013). This process improves the justification of selecting design iterations by measuring human satisfaction. It can be applied as a quantitative method for measuring MAR application effectiveness using ratio scales to stray from subjective opinions. The rating system works with a set criteria, to which a number of 1 to 10 is assigned to each heuristics. When the value is allocated as 1, there would be a need for improvement, whilst 10, is most effective. Design iterations can then be measured and analysed, based on these ratings, to establish the best performing prototype. This model informs understanding and should be customised to address the project specific requirements of application usability and visual and cognitive limitations.

6. Case Study

Working in collaboration with PTW Architects, three conceptual MAR UI prototypes were developed following the mixed methods. The initial stage involved developing a customised heuristic set to define key objectives of the iterative design process. Two prototypes were then designed accordingly in Adobe Experience Design CC (Beta) 2017 and a simulated UX was achieved through the InvisionApp platform. Prototype C was realised through an experiment where limitations of prototype A and B were analysed and evaluated to validate improvements of prototype C.

6.1 CUSTOMISED HEURISTICS SET

Heuristics 1 to 5 focus on usability performance, while 6 to 10 focus on visual and cognitive aspects (Table 1). This set develops a framework to address what criteria can be applied to MAR applications.

TABLE 1. Customised heuristic set.

Heuristics	
1	Reasonable waiting times
2	Support user’s concept learning
3	Visual cues to influence experience
4	Clear warning and exit messages
5	Consistent button sizes
6	Navigation simplicity
7	Applies Gestalt laws
8	Multiple levels of detail
9	Aesthetic and minimalist design
10	Designed for context

6.1.1 Heuristic Justifications

The list selects heuristics based on their appropriateness for project objectives. With the intention of establishing an optimised list for the purpose of MAR UI development in an interior design context. It also provides a basis for the iterative design development process, as they can be used as a benchmark for measuring the effectiveness of MAR application prototypes.

The heuristics are justified based on their relevance to MAR UI design and the project context:

1. Although waiting times will be simulated, this is a major factor in MAR application design, as users should be able to quickly complete designs, as it is in real-time. This heuristic may be more relevant to further work in the MAR application process.

2. Concept learning reduces time taken to complete a task in a given application, thus overtime the tool will be more efficiently used. Familiar icons support cognitive functions and enhance learnability.

3. Important for the flow of information to be accurately presented to the user. It engages the user as it reduces confusion and uncertainty while completing tasks.

4. Providing user’s clarification of their actions can improve UX. Especially important in MAR applications, as users are customising their work according to their personal preferences, a sudden exit by accident can be disastrous in this context.

5. Consistency of button size is key in achieving an aesthetically appealing UI as it presents itself as clear and straightforward.

6. How well a user can navigate through an application influences the UX. This flow can be enhanced by addressing other heuristics which can include a simplistic design and additional visual cues for example.

7. Essential in ensuring users are able to easily navigate the controls on the MAR applications UI. Placement and order of these controls is essential in enhancing usability and visual appeal.

8. In the context of interior design, level of detail is essential as it suggests the importance of a basic and advanced interface for different experience level users.

9. To ensure users are not overwhelmed with the amount of content on any given screen, a simplistic and minimalist design is essential. It is important to present controls in an organised manner to enhance user workflow.

10. Important to include users in the iterative design process of UI and UX development as the intended demographic will provide insight to their

needs and suggestions for a design tool. Designing for context allows users to make the most of the application as it has a purpose in the design process.

6.1.2 Defining the Questionnaire

Drawing influence from customised heuristic set to formulate the questions for the questionnaire (table 2). Heuristic 4, 7 and 8 were not assigned a specific question.

TABLE 2. Heuristic influences on questionnaire.

Heuristic addressed	Formulated Question
1	Q1 Was there a reasonable loading waiting time?
3	Q2 How familiar were you with the terms and symbols used?
2	Q3 Was the design suggestive of what you could do text?
6	Q4 Did you find the given tasks easy to do?
5	Q5 How consistent were the button sizes?
6	Q6 How simple was the overall navigation?
9	Q7 How aesthetically pleasing is the overall interface?
10	Q8 How well designed is the application for the purpose?

6.2 EXISTING APPLICATIONS TECHNOLOGY REVIEW AND COMPARISON STUDY

Measuring the usability and visual and cognitive aspects of existing MAR applications, or similar, using customised heuristics as previously defined (table 3). The software explored include: Augment, Graphisoft BIMX, MagicPlan, Ikea Catalogue and Layar (Appendix A: Technology Review: Exploration into existing MAR applications).

TABLE 3. Comparison study of existing applications measured against customised heuristics.

Application	**Usability**					**Visual and Cognitive**				
	1	2	3	4	5	6	7	8	9	10
Augment	●	●	○	●	●	●	●	○	●	●
Graphisoft BIMX	●	○	○	○	◐	○	◐	○	◐	●
MagicPlan	●	◐	◐	◐	◐	○	◐	○	○	◐
Ikea Catalogue	●	●	●	○	○	○	○	○	●	○
Layar	●	●	○	●	●	●	●	○	●	●

6.3 PROTOTYPING WORKFLOW

Multiple software including Adobe Experience Design CC (Beta) 2017, Adobe Dreamweaver CC 2017, Webflow and InvisionApp, was investigated to determine which is the most suited for the design project requirements. It was found that Adobe Experience Design CC (Beta) 2017 in combination with InvisionApp is the most accessible and time efficient prototyping tools to adhere to time constraints of the project.

6.3.1 The Iterative Design Process

The iterative design process, defined in the methodology, shows the interconnecting sequential process to achieve each prototype. The process is further simplified to represent the progression of the iterative design workflow (figure 4).

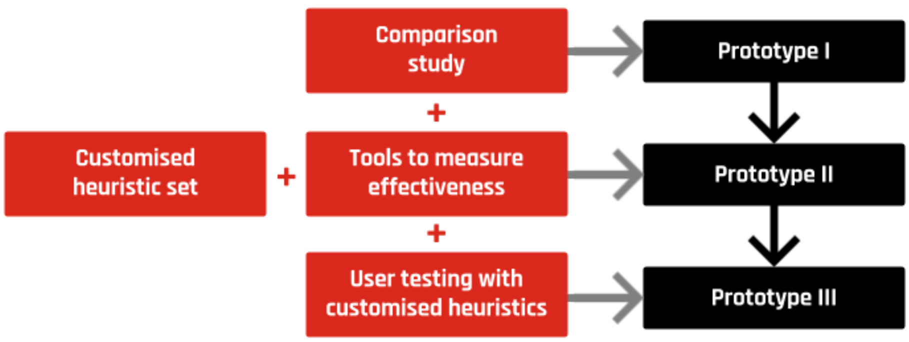

Figure 4. Layered iterative design process.

6.3.2 UI Software

Adobe Experience Design CC (Beta) 2017 was used to iterate UI layouts for each prototype. It allowed for the exporting of PNG or JPEG file formats to be quickly generated for InvisionApp. While having the ability to assign buttons and gestures within this software, accessibility to a device with iOS 10.0+ or android with 5.0 and up restricted ability to display the UX on available tablets.

6.3.3 UX Software

InvisionApp was used to simulate the UX of each prototype to explore the functionality and flow of the system. It converts PNG and JPEG to a simulated working application. It works with layers, where each screen hosts "hotspots" as buttons or gestures as triggers to redirect to other layers in the prototype, giving the impression of a working application. To share the prototypes, the application is available to be viewed on any device through a web link.

6.3.4 Platform

A tablet was used as the consistent size for the UI screens in the landscape format. Landscape appeared more appropriate for the context of the application as it provided more working space on the screen. An IPad tablet was used as it was accessible at the time of the project.

6.4 PROTOTYPE A

A customised heuristic set defined the objectives for prototype A (table 1), to constrain the design solutions to principles that are viable for MAR UI. The comparison study also highlighted successes and failures as they were measured against the same list of customised heuristics (table 8). The initial planning stages involved a low fidelity prototype where screens were sketched out to visually represent the UI and UX (figure 5).

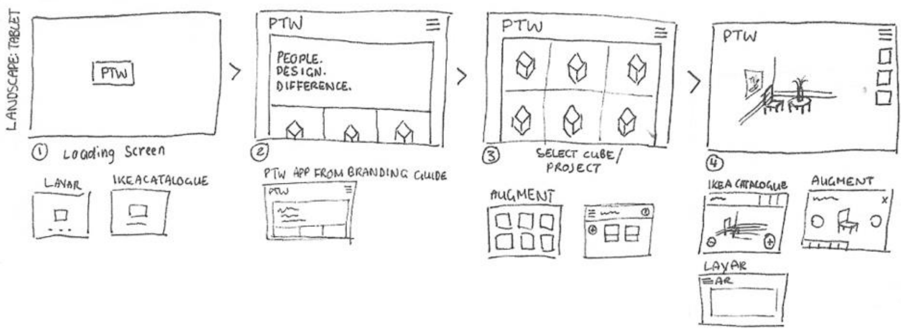

Figure 5. Low fidelity UI prototyping showing the flow of the intended UX.

The main focus of this iteration was to cater for the context, and to explore the basic functionalities of the application and the flow of the UX. It was with an aim to highlight key functionalities in a minimalist way to improve the UX and reduce confusion (figure 6, 7, appendix C, figure 23, 24).

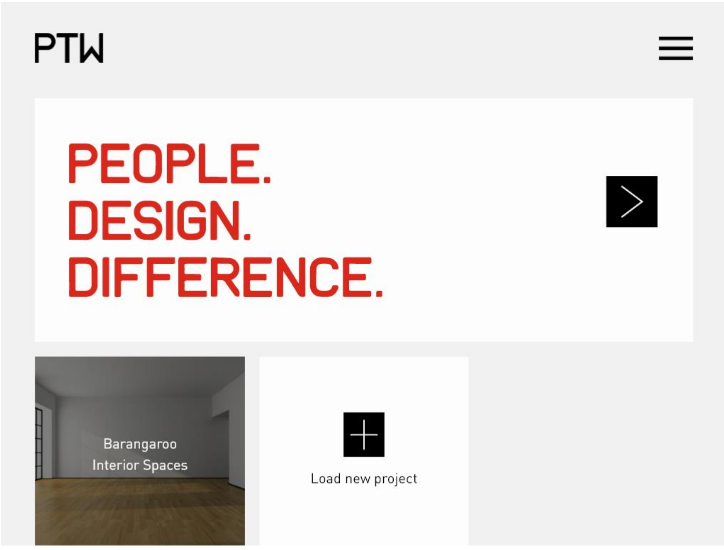

Figure 6. Prototype A: Home screen.

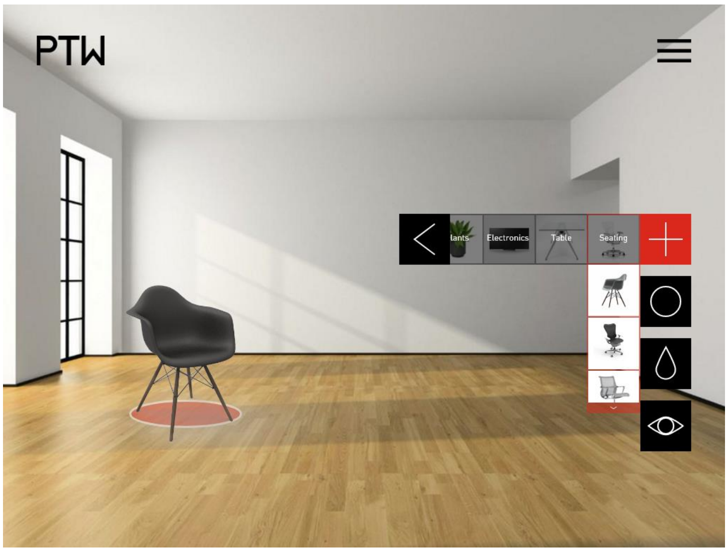

Figure 7. Prototype A: Screen viewer with open furniture drawer.

6.5 PROTOTYPE B

Prototype B combines functionality of prototype A, but places it in a more refined UI. It promotes the context through its aesthetically appealing interface and improved UX. A different impression is achieved in the steps of opening a project (figure 8 and appendix D, figure 25), but the 'screen viewer' remains similar to that of prototype A (figure 9 and appendix D, figure 26).

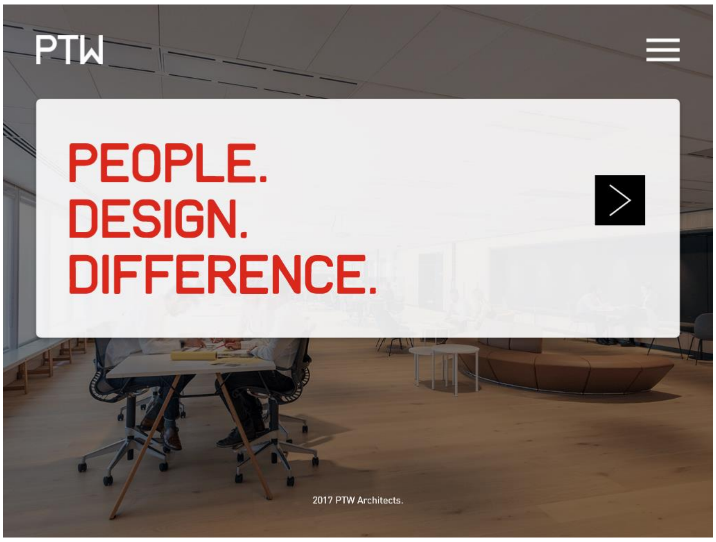

Figure 8. Prototype B: Home screen.

Figure 9. Prototype B: Screen viewer with open placeholder drawer.

6.6 USER TESTING WITH CUSTOMISED HEURISTICS

User-testing commenced after the completion of prototype A and prototype B. The user-testing is discussed in terms of an experimental investigation into evaluating the effectiveness of UI and UX design of MAR applications. The customised set of heuristics provide a predicted evaluation of the application performances prior to user testing, the experiment aims to validate these limitations and achieve user friendly solutions.

6.6.1 The Experiment: Measuring 'Effectiveness'

An experiment using inspection methods to better understand how to apply heuristic evaluation with low experience users in the context of interior design testing UI and UX of MAR applications. This experiment aims to define a method of measuring application effectiveness by:

1. Identifying usability performance limitations
2. Identifying visual and cognitive limitations
3. Identifying the 'effective' and 'ineffective' aspects through a questionnaire completed by participants that are a part of the relevant demographic
4. Validating improvements to inform prototype C

TABLE 4: Experiment Aims and Methods.

Data Type	Aims	Data Collection Method
Quantitative	1, 4	Using AHP model (appendix B, figure 21) and measuring against customised heuristics (table 2).
Quantitative	2, 4	Using AHP model (appendix B, figure 21) and measuring against customised heuristics (table 1).
Qualitative	3, 4	Based on questionnaire (appendix B, figure 22) from those a part of the relevant demographic (figure 10).
Quantitative	1, 4	Number of taps taken to complete task was recorded on video for documentation purposes and review.
Quantitative	1, 2, 4	Time taken to complete task was recorded on video for documentation purposes and review.
Qualitative/ Quantitative	4	Mixed methods, all of the above.

6.6.2 The Experiment: Participant Requirements and Demographics

It was important to select homogeneous participants to normalise the demographics of the experiment, and select those who are in an occupation related to the context of the project (figure 10). This is because the usability of the application must "consider the context in which the system will be used" (Stone et al, 2005). Here, participants were chosen on the basis that:

- they are employed at PTW Architects,
- have adequate knowledge of the use of technological applications,
- support the means of the research focus.

There were 15 participants who took part in the study, a number and colour has been assigned to each participant to protect their identities.

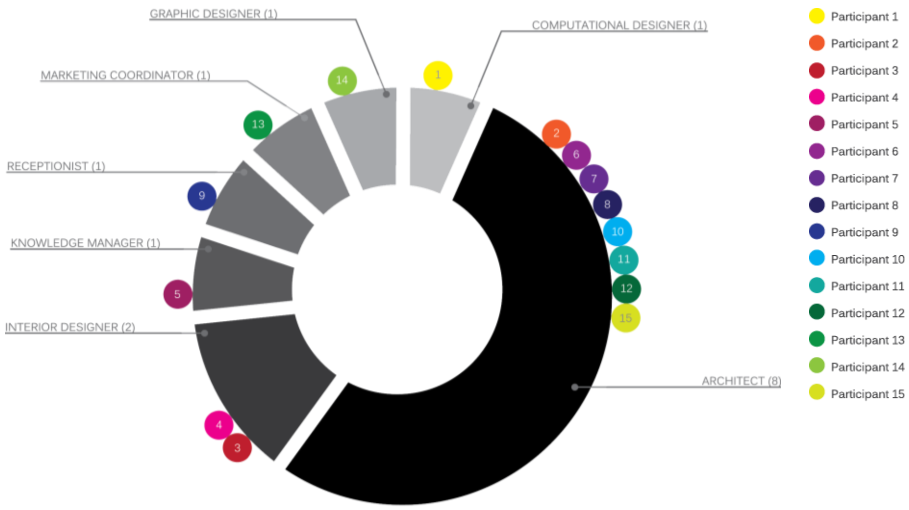

Figure 10. Participant demographics.

6.6.3 The Experiment: Standardising Procedure

Each interview took between 15 and 30 minutes to complete. Each participant was given the same introductory debrief about the project, and the tasks were given in the same order. By standardising the procedure of each participant interview, it minimises the chance of variation and bias (table 5).

TABLE 5. Experiment procedure.

Time (min)	Task description
2	Debrief of project purpose and participant tasks
1	Sign participant information statement and consent form

3	Prototype A task Choose a space to view Locate the scene viewer Place a chair in the scene
3	Prototype B task Choose a space to view Locate the scene viewer Place a chair in the scene
6	Complete questionnaire and / or further discussion and / or questions with the researcher Participants can review prototypes on given reference sheet

6.6.4 Quantitative Data Collection

Quantitative data included:

1. Tap counts: how many times a participant tapped the touch screen, counting stops when they have achieved the task requirements (figure 11, 12 and 13).
2. Time taken: how many seconds the participant took to complete the set task/s, timer begins at first tap on the screen until the last tap that completes the task (figure 14, 12 and 13).
3. Ratings using AHP model (appendix B, figure 21): the value the participant ‘rated’ each heuristic (criteria) aspect based on their experiences (figure 15 and 16).

6.6.5 Anticipated Quantitative Results

To compare the success of a users’ ability to complete tasks at ideal rates, the anticipated tap count and time taken for both prototype A and prototype B have been recorded (table 6). The anticipated rate is the minimum tap count and time taken for a user to complete the task requirements. Anticipated tap counts remain the same in both prototypes due to the same number of steps required to complete the given task.

TABLE 6. Anticipated tap count and time taken to complete task.

Prototype	Anticipated Tap Counts	Anticipated Time Taken (s)
A	9	34
B	9	34

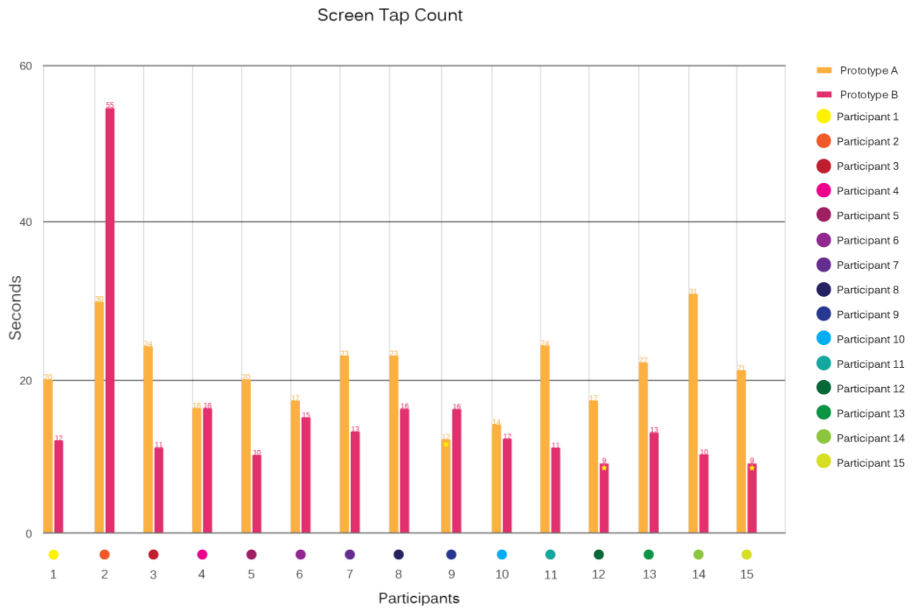

Figure 11. Prototype A and Prototype B: Tap count comparison.

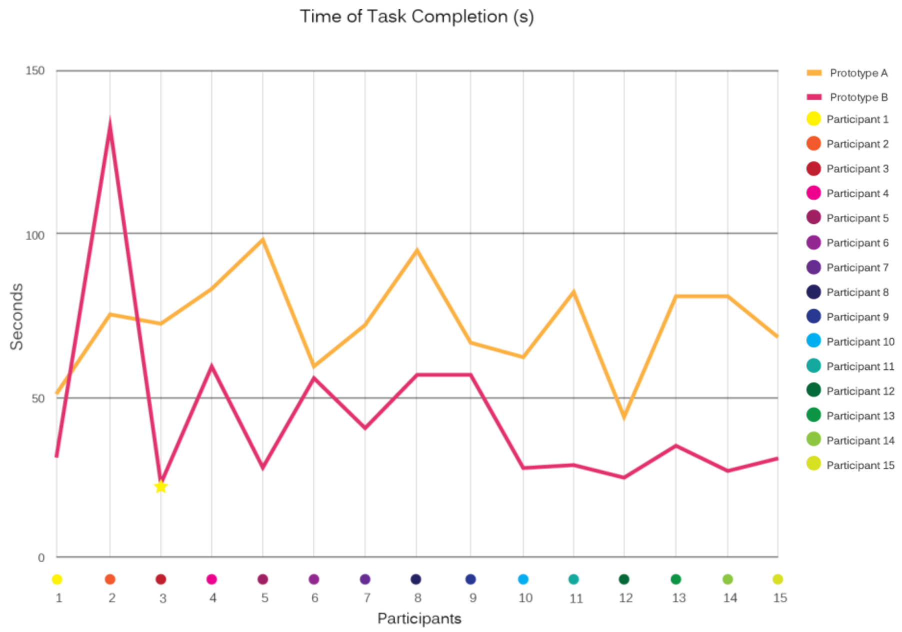

Figure 12. Prototype A and Prototype B: Time of task completion comparison.

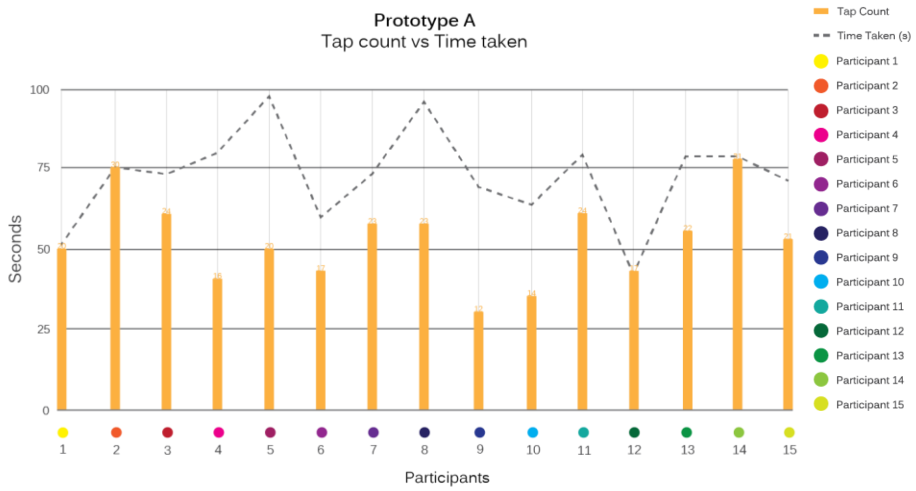

Figure 13. Prototype A: Tap count versus time taken.

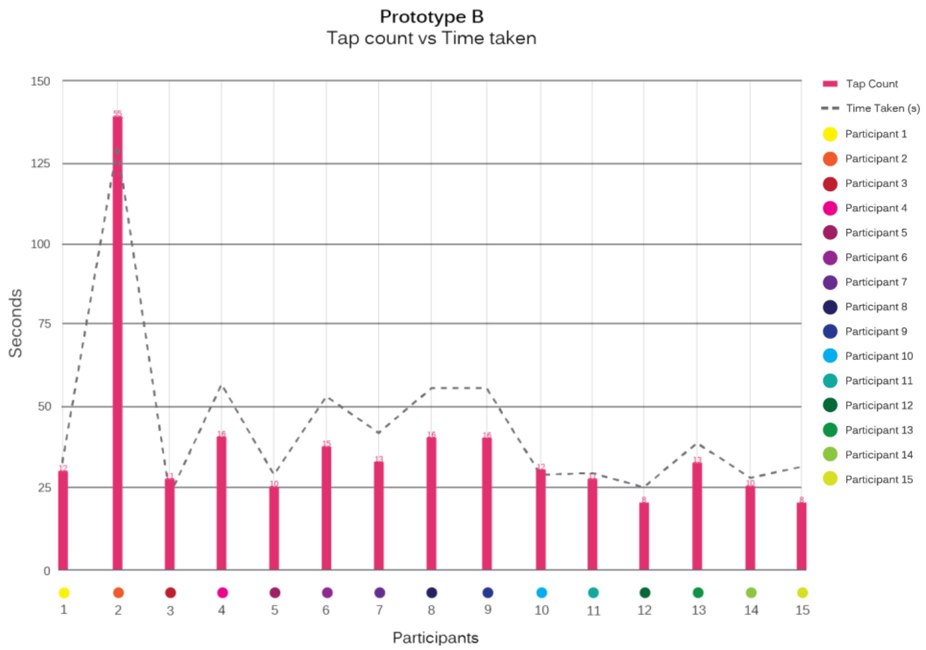

Figure 14. Prototype B: Tap count versus time taken.

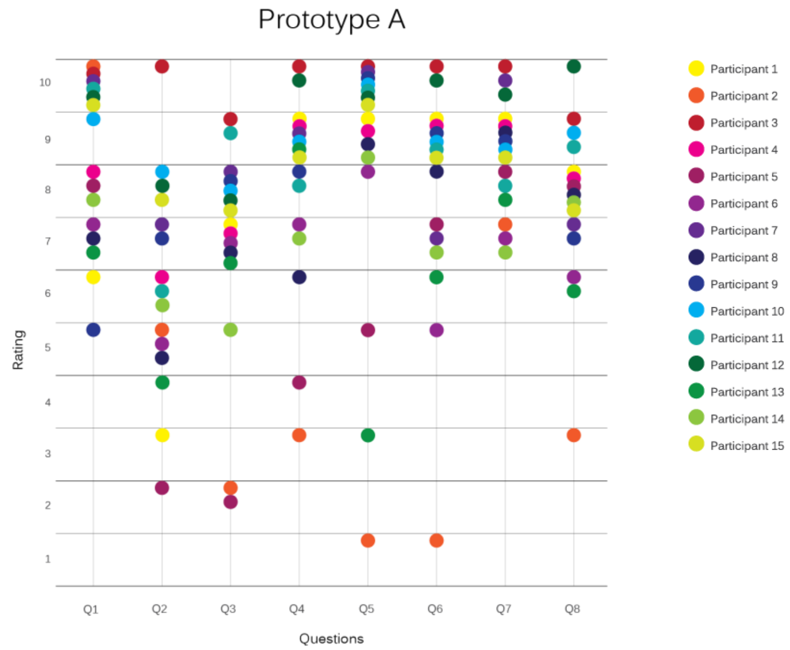

Figure 15. Prototype A: Rating results using AHP model (appendix B, figure 21) with customised heuristics.

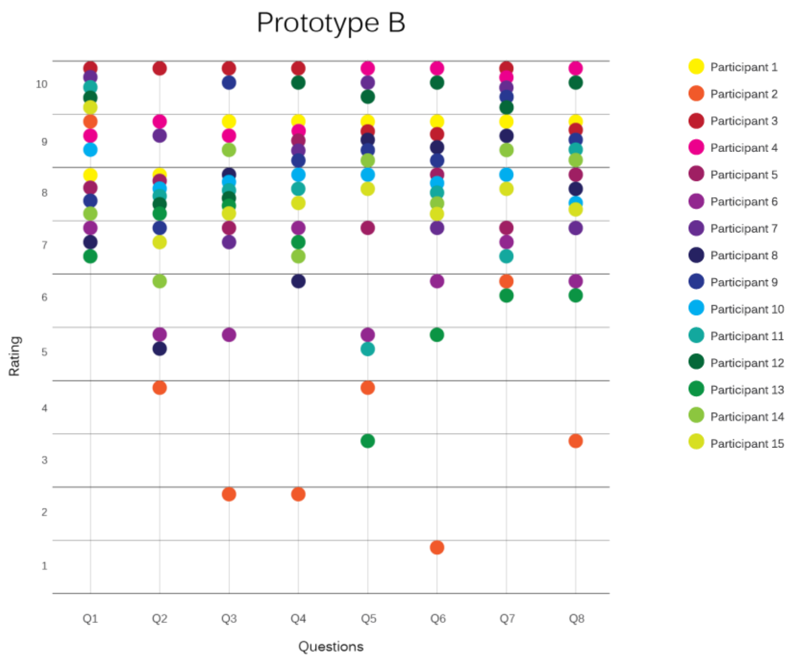

Figure 16. Prototype B: Rating results using AHP model (appendix B, figure 21) with customised heuristics.

6.6.6 Qualitative Data Collection

1. Questionnaire (appendix B, figure 21): the written data collected from questions completed after experiencing both prototype A and prototype B (figure 17).
2. Preference: subjective opinion of their preferred prototype (figure 18).

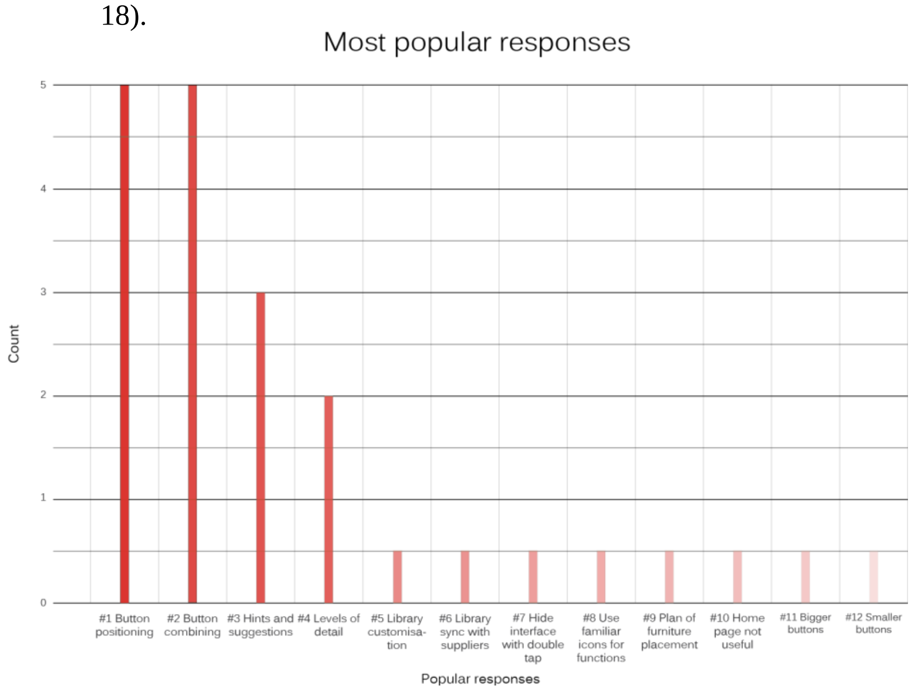

Figure 17. Most popular responses collected from the questionnaire.

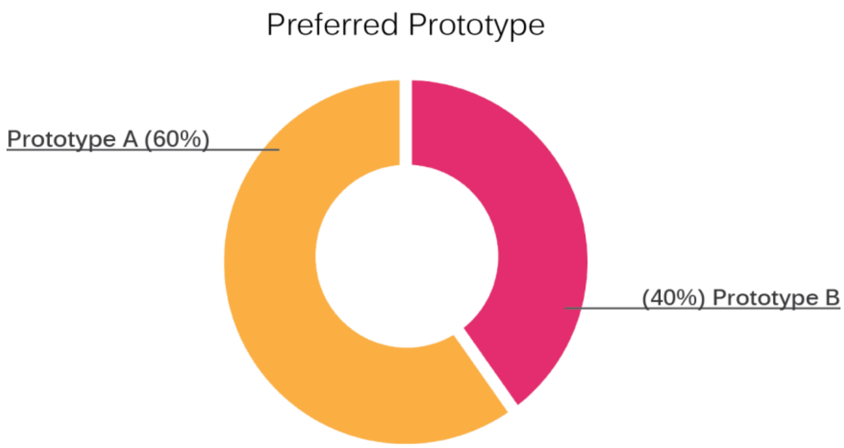

Figure 18. Preferred prototype collected from 15 participants.

6.7 EXPERIMENT OUTCOMES

6.7.1 Quantitative Data Outcomes

As shown in figure 11, no participants using prototype A achieved the anticipated rate of 9 tap counts, the minimum was 12, by participant 9. However, in prototype B, two participants achieved the anticipated rate of 9 tap counts, this was set by participants 12 and 15.

According to figure 12, no participants using prototype A achieved the anticipated time taken of 34 seconds. While 8 participants, participants 1, 3, 5, 10, 11, 12, 14 and 15 using prototype B, beat the anticipated time taken of 34 seconds.

In figures 13 and 14, prototype A's mean tap count was 21 while the mean time taken was 73s. While in prototype B, the mean tap count was 15 and the mean time taken was 44s. A difference of 6 taps and 117s, possibly due to a learning effect of being introduced to a similar user interface in prototype A.

In figures 15 and 16, it was found that participants rated prototype B higher, but they still chose prototype A as the most preferred application. Results varied between all participants, although it provides a gage of user satisfaction and the application 'effectiveness' and within the demographic.

6.7.2 Qualitative Data Outcomes

In figure 17, 'button positioning' of the order of commands should be swapped, where placeholders appeared first and furniture drawer appeared second, as buttons should be in the order a user is expected to use them. 'Hints and suggestions' also a major aspect of improving ease of use. As well as, varying 'levels of detail' would assist with different user experience levels. These results suggested ideas to improve the application system to be more specific to their occupations.

In figure 18, those who preferred prototype A was due to its simplicity and ease of use rather than its aesthetics. Participants choosing prototype B thought the aesthetics of the UI were more appropriate for the context of the application and that the layout was more user friendly.

6.8 PROTOTYPE C

As a result, a collection of specific usability and visual and cognitive limitations were highlighted in the experiment, where improvements were implemented in prototype C (table 7). It is a more refined prototype which covers the needs and requirements of the demographic (appendix E, figure 27, 28, 29).

TABLE 7. Prototype C application improvements.

Popular responses addressed	Source gathered from	Heuristics addressed	Improvement
#3	Qualitative data	2, 3, 4	Added warning messages throughout experience.
#3	Qualitative data	2, 3	Added help suggestion when application is first opened.
#11	Qualitative data	7, 9, 10	Furniture drawer and materials drawer have been enlarged and are viewed on a larger portion of the screen.
#1	Qualitative data	2, 6	Swapped button positioning of placeholder and furniture drawer.
#10	Qualitative data	3, 10	Added description on home page.
#8	Qualitative data	2, 3, 6, 9, 10	Changed main function icons in the screen viewer.
#9	Qualitative data	10	Change map viewer to show plan of placed items in the selected room.
-	Quantitative data	2, 6	Reduced steps to achieve task (reduces tap count and time taken).

Prototype C's UI is therefore considered more effective in comparison to prototype A and B, due to it successfully applying more of the customised heuristics to its UI and UX (table 8). However, further prototyping can achieve the quintessential result of an interior design MAR application.

TABLE 8. PTW Interior Design application prototypes A, B and C comparison against customised heuristics using AHP model.

Application	**Usability**					**Visual and Cognitive**				
	1	2	3	4	5	6	7	8	9	10
Prototype A (figures 6 and 7)	●	◐	○	○	●	●	◐	○	◐	◐
Prototype B (figures 8 and 9)	●	◐	◐	◐	●	◐	●	○	●	●
Prototype C (figures 19 and 20)	●	●	●	●	●	◐	●	◐	●	●

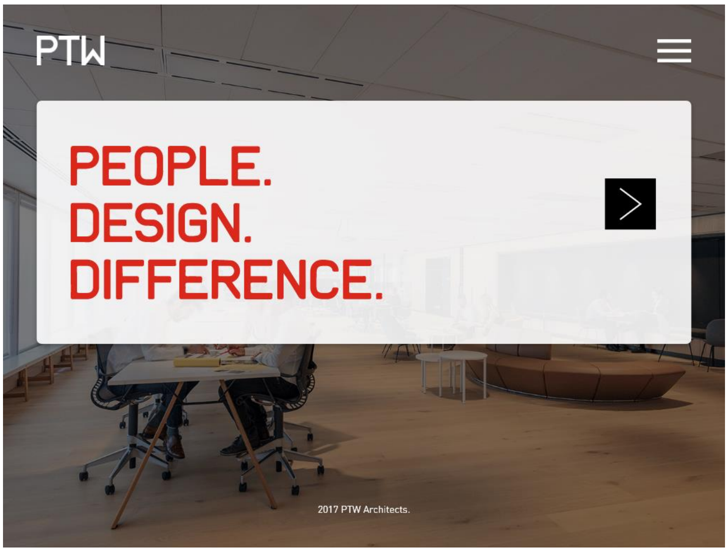

Figure 19. Prototype C: Home screen.

Figure 20. Prototype C: Screen viewer with open placeholder drawer.

7. Significance of Research

Often poor UI design can lead users' to feeling frustrated and dissatisfied with an application, as it may not have promoted self-efficacy, or allowed them to achieve the task they intended to do (Stone, 2005). To support the development of more effective UI and UX in MAR applications, the design research project provides an iterative design development process and an evaluation technique to measure application effectiveness between prototypes. The evaluation method outlines and discusses an MAR criteria customised specific to the requirements of the design project. By suggesting methods of testing for poor UI design, it substantiates a validation approach of evaluating UI design in an iterative design process.

Such methods have the potential to cover the fundamentals of a design development process for MAR UI and UX design. Through action research, a model interior design application for PTW Architects was developed based on scholarly research into guidelines to enhance designer and client communication. Not only does the finalised model promote a creative way of combining AR in the design process, it provides an evaluation method which can be applied to any context. Therefore, this research aims to support the continuous development of effective UI and UX design of MAR applications used in the architecture industry.

8. Evaluation of Research Project

This research defined a process for the development and testing of MAR applications by providing essential methodology of constructing various UI's and a model for measuring application effectiveness. It applied existing inspection methods to consolidate a foundation for developing MAR applications in the context of interior design. Here, it is through user-testing, and evaluation of the data sets collected that provided insight into key improvements that could be made to develop the final prototype.

The participants in this study included a small sample size of 15 PTW employees from a variety of design based occupations, therefore it is essential to continue research into applying these methods to a larger sample size with a longer project duration. This research has set out the fundamental requirements of user-testing and experiment procedures. However, this study covers one half of the targeted demographic; the designers. Further work is needed in testing with a clientele demographic but this additional research could benefit from altering procedures to relate more to the clientele market. This would create a balanced study that provides insight into two different experience and skill levels, which would highly influence the content of the generated prototypes and further refine their validity in the iterative design process. Testing with the designer first simplifies the application, before testing with the client using a more refined prototype, this way, a baseline is determined of what tools are most essential in different levels of detail.

Although, a limitation of this research was the need to simulate a UX through external platforms (InvisionApp) due to strict time constraints. This research covers the front end design aspect, as it is a part of a larger project scope, so further work is needed to translate this project into a working MAR application by combining with the back end AR component.

At this stage, a customised set of heuristics was used to evaluate the effectiveness of MAR UI's through user-testing with designers. Applying heuristics at the beginning of the design process may provide immediate validation, however, heuristics as an inspection method working in conjunction with user-testing is a workflow that proved effective for the aims and time constraints of this project (appendix F, figure 30). The documentation of the experiment was key in evaluating the effectiveness of user applications, as with this knowledge it can support further studies into UI and UX design, to be a step closer to reducing user frustration of MAR applications.

9. Conclusion

In evaluating the design project, the methodologies played a major role in identifying limitations of prototypes during the iterative design processes. The experiment found that users responded best to experiences involving visual cues or suggestive gestures to guide them through an application. Also providing users with clear warning and exit messages is also beneficial to troubleshoot implications. Both findings were gathered through observation and evaluation of qualitative data collection. Qualitative data collection provided more insight into the minds of the intended demographic. Through the integration of heuristics into the questionnaire, it directed the feedback content. The quantitative data collection aligned with the customised heuristics, provided an insight in the effectiveness of the application. The application effectiveness was examined through a variety mixed method approach which consisted of; experiments, surveys and inspection methods. It was found that the most appropriate approach for the context of the project was mixed methods, as it directed a non-bias approach for the participants. The paper further suggests a method of justifying a suitable list of criteria in the context of interior design. This determined that using heuristics customised for a particular project is more appropriate over generic lists of heuristics. The processes discussed in this paper can be applied to multiple scenarios as it provides a benchmark for future UI and UX studies of MAR applications. Therefore, it is evident that the research provides a fundamental understanding of the requirements to achieve an effective UI and UX in MAR applications. Providing an insight for opportunities within AR technologies, utilised as a design communication tool in an interior design context.

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Image References

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Unknown (2017). Empty Room. [image] Available at: https://goo.gl/8fFsq1 [Accessed 22 Sep. 2017].

Glossary

AR	Augmented Reality
MAR	Mobile Augmented Reality
UI	User Interface
UX	User Experience

Appendices

APPENDIX A: TECHNOLOGY REVIEW OF EXISTING MAR APPLICATIONS

TABLE 9. Technology review of existing MAR or similar applications.

Application	Description	Positives	Negatives
Augment	MAR application that allows users to visualise to scale 3D models in AR.	• Simple interface / navigation • Android login screen with transparent backdrop is effective and aesthetically pleasing • Self-explanatory usability and interface functions	• Some instructions on main interface displaying objects is unclear as did not display properly on an android device
Graphisoft BIMX	Visualisation platform for both 2D and 3D data; models and documentation.	• Interface layout is appropriate for context • Good display of hierarchical information • Control gestures are effective	• ‘Walking’ icon isn't very visible in the bottom right corner • Does not highlight selected targets • Too many functions visible • High physical effort required
Magicplan	Measures rooms using AR to generate floorplans.	• Variety of tools presented • Customisable toolset - It asked for an occupation, and	• Interface can become overwhelming due to many options and settings

		allowed tools to be selected that would be relevant to the selected industry	• Accidently brought up a tutorial giving me instructions to draw rooms after already figuring it out. The gesture to open this feature is unclear
Ikea Catalogue	MAR application that allows users to place Ikea furniture to scale in AR.	• Walk-through of application with visual cues was effective • Simple interface and buttons • Pop up of more information when tapped, keeping screen clean	• On smaller devices, text becomes hard to read and is too small
Layar	MAR application that scans digital or printed documentation that has been enhanced to view overlaid digital experiences.	• Shows purpose through clean interface • Clean and simple interface • Very easy to navigate • Instructions and prompts	• N/A – No problems were identified

APPENDIX B: EXPERIMENT DATA COLLECTION: USER-TESTING QUESTIONNAIRE

Questions	Ranking (Please tick)									
	1	2	3	4	5	6	7	8	9	10
1. Was there a reasonable loading waiting time?										
2. How familiar were you with the terms and symbols used?										
3. Was the design suggestive of what you could do next?										
4. Did you find the given tasks easy to do?										
5. How consistent were the button sizes?										
6. How simple was the overall navigation?										
7. How aesthetically pleasing is the overall interface?										
8. How well designed is the application for the purpose?										

← Needs improvement Effective →

Figure 21. Quantitative data collection documentation format following AHP model.

9. Any suggestions / ideas / improvements / comments:

10. Which prototype did you prefer and why? Prototype A / Prototype B (Please circle)

Figure 22. Qualitative data collection documentation format.

APPENDIX C: PROTOTYPE A USER INTERFACE

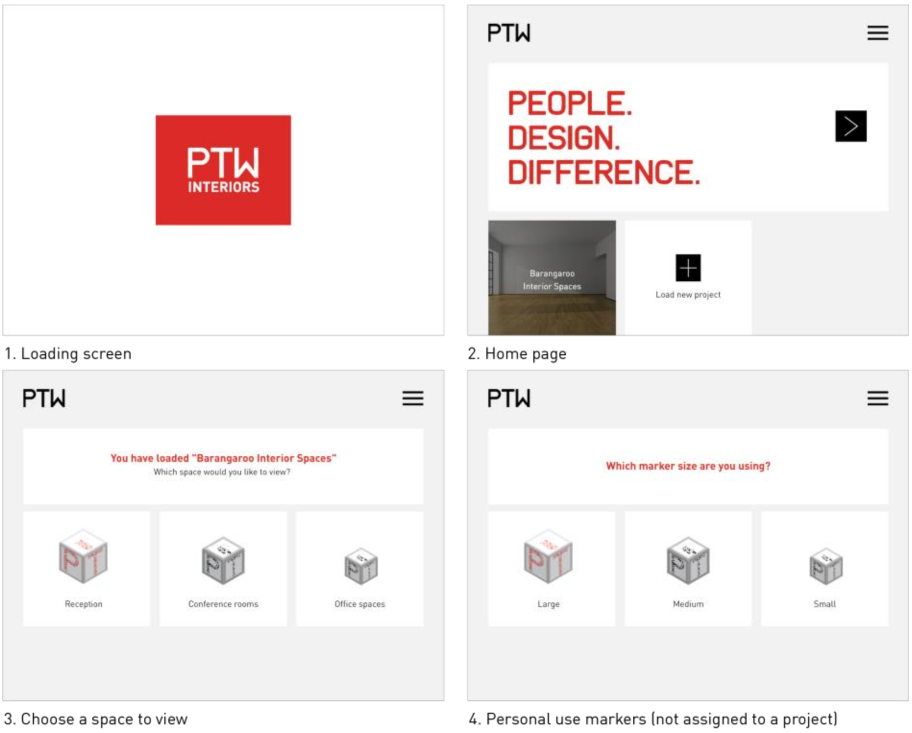


Figure 23. Prototype A: Process of selecting a project to view.

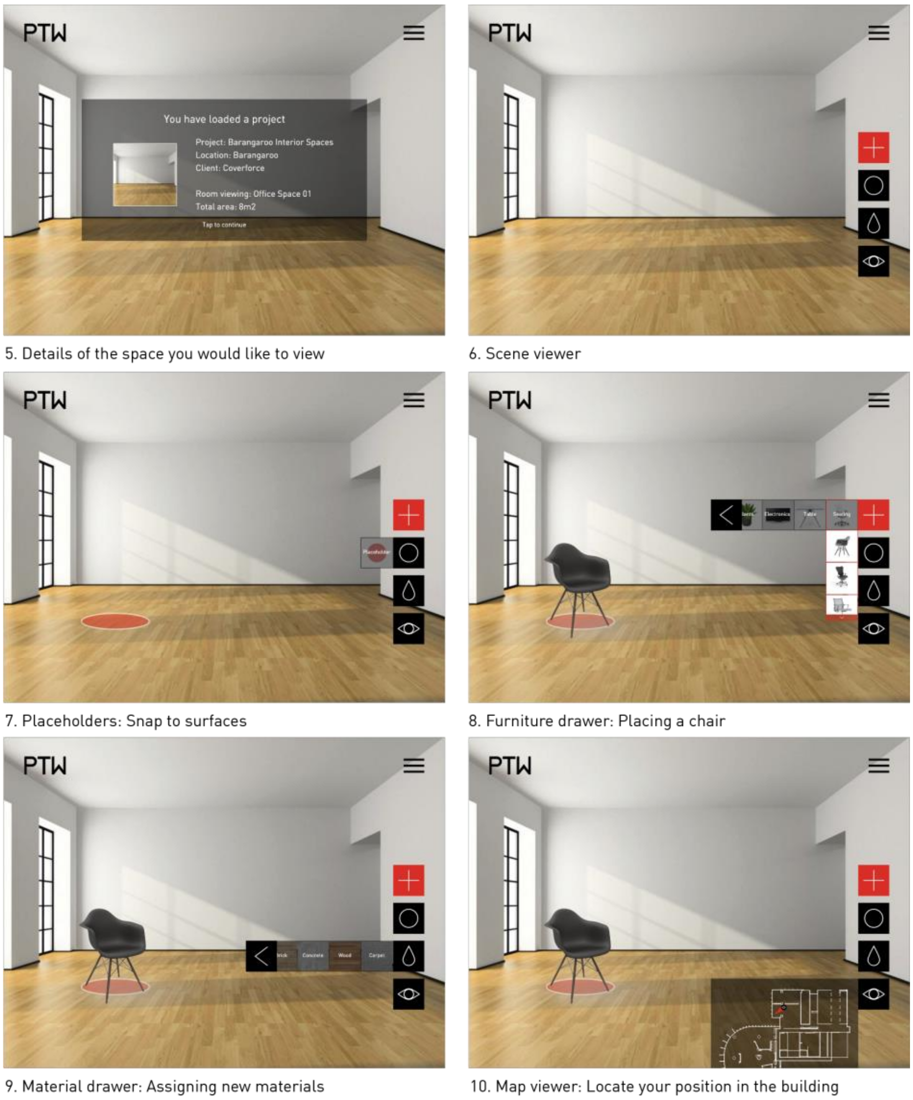


Figure 24. Prototype A: Accessing the scene viewer.

APPENDIX D: PROTOTYPE B USER INTERFACE

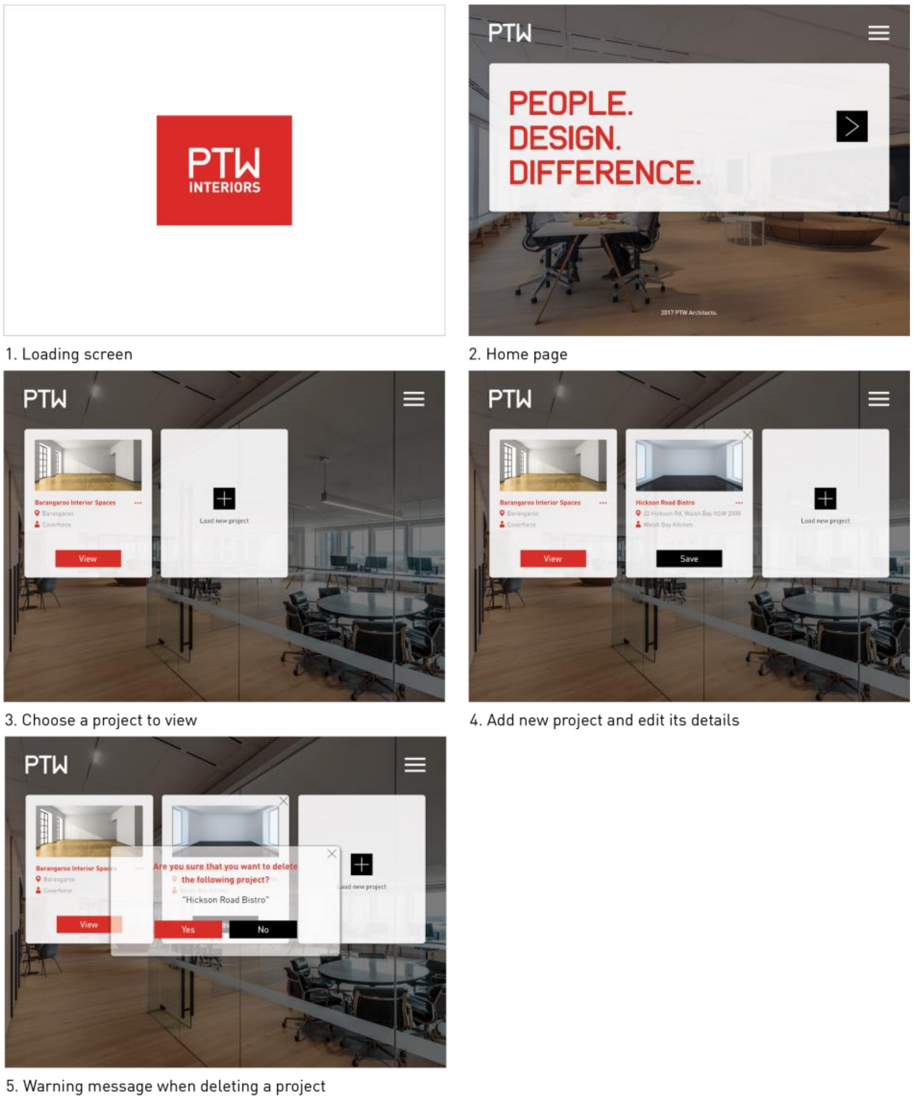


Figure 25. Prototype B: Process of selecting a project to view.

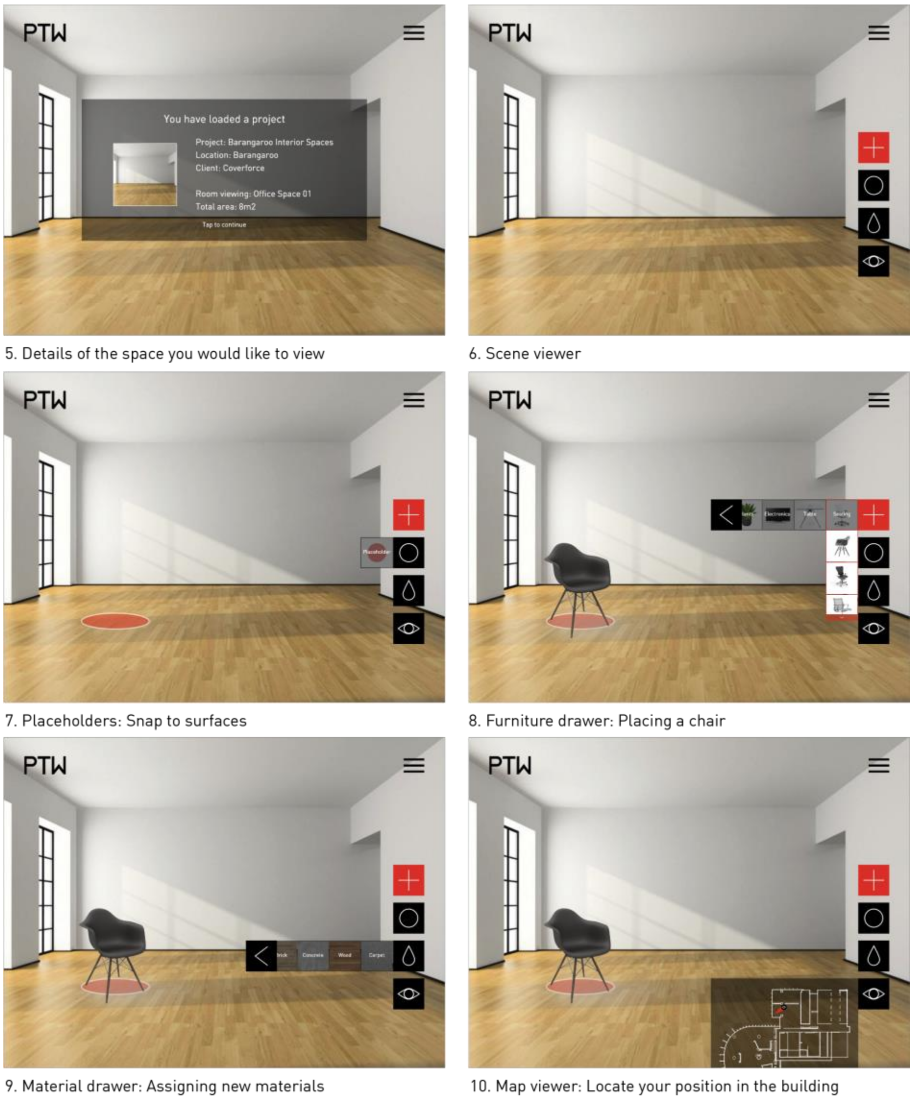


Figure 26. Prototype B: Accessing the scene viewer.

APPENDIX E: PROTOTYPE C USER INTERFACE

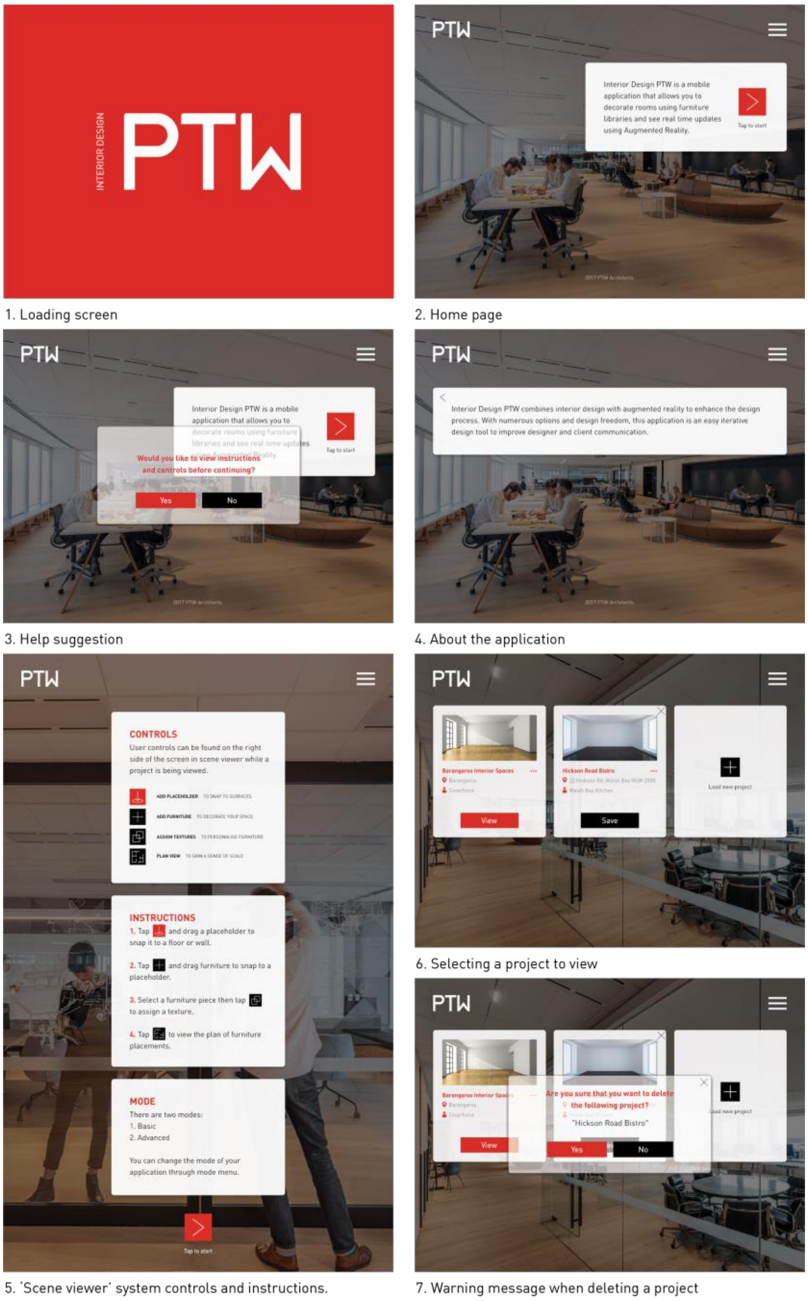


Figure 27. Prototype C: Process of selecting a project to view.

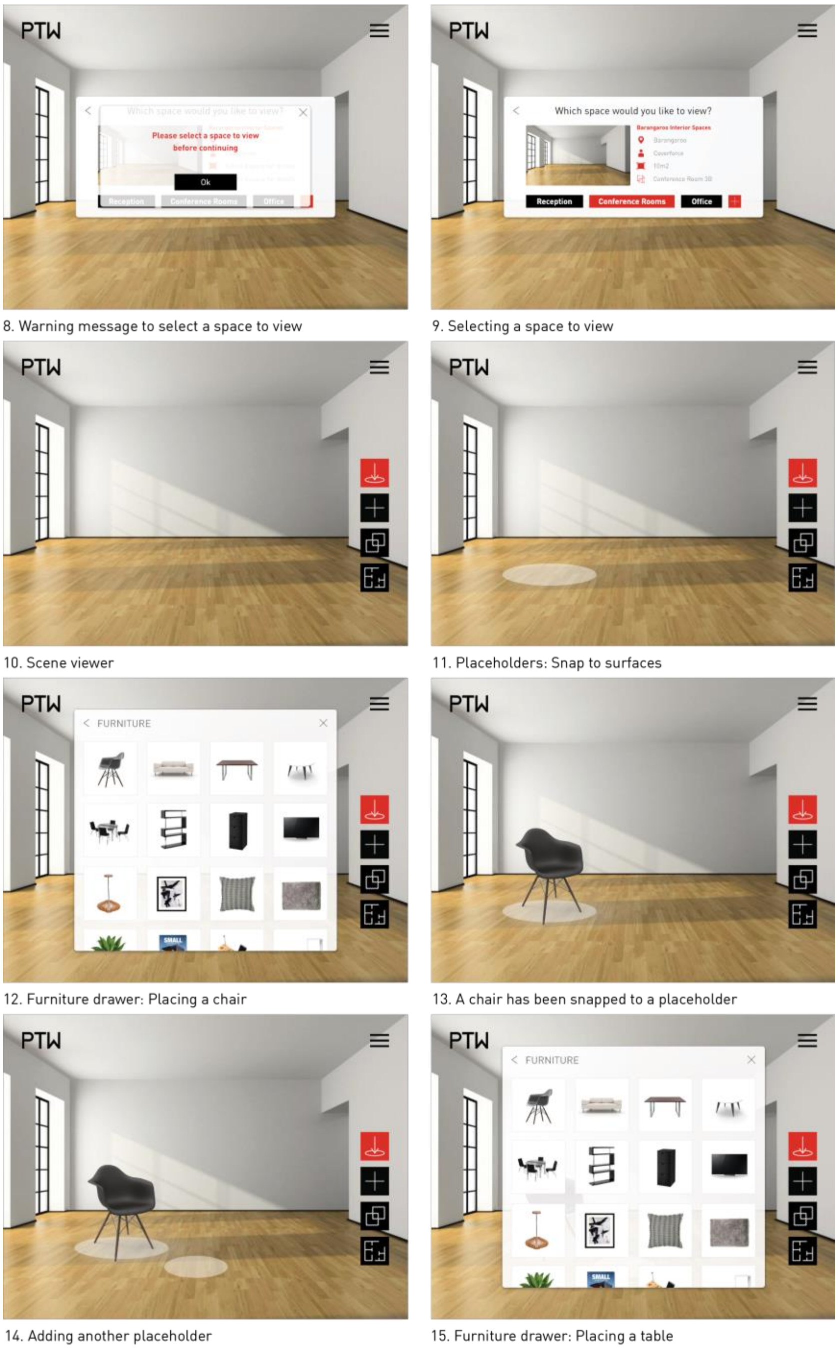
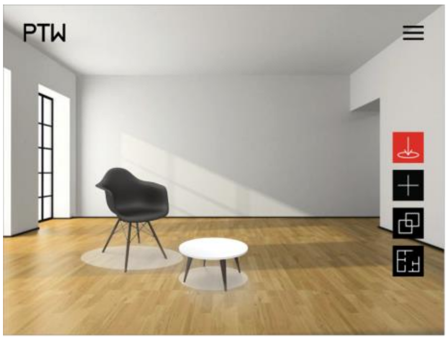
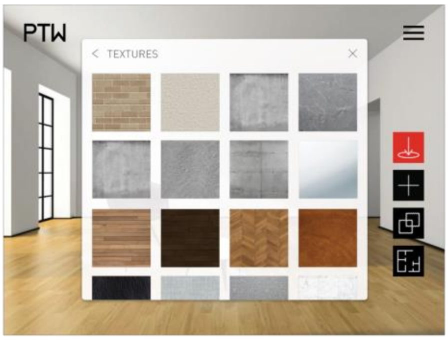


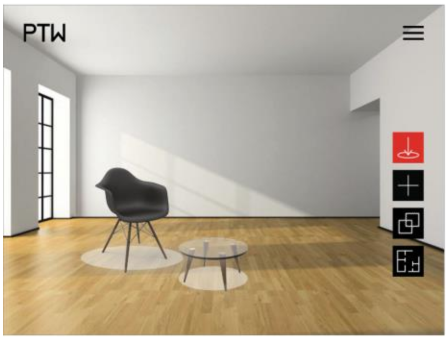
Figure 28. Prototype C: Accessing the scene viewer.



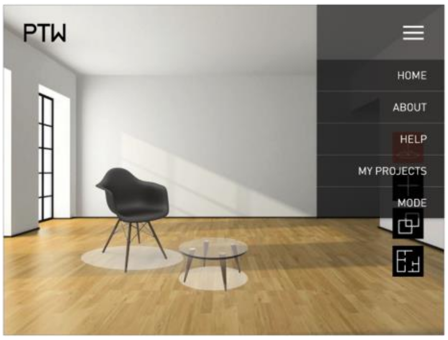
16. A table has been snapped to a placeholder



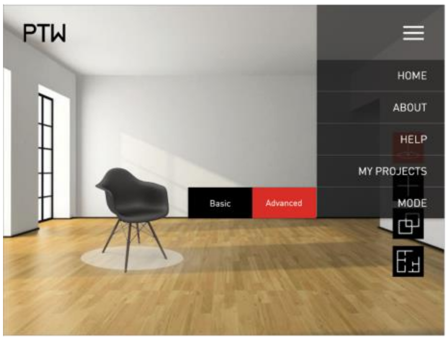
17. Material drawer: Assigning glass to the table top



18. Assigned a new material to the table



19. Accessing the drop-down menu



20. Level of detail: Assigning different modes

Figure 29. Prototype C: Accessing the scene viewer continued.

APPENDIX F: PROJECT LYREBIRD TIMELINE

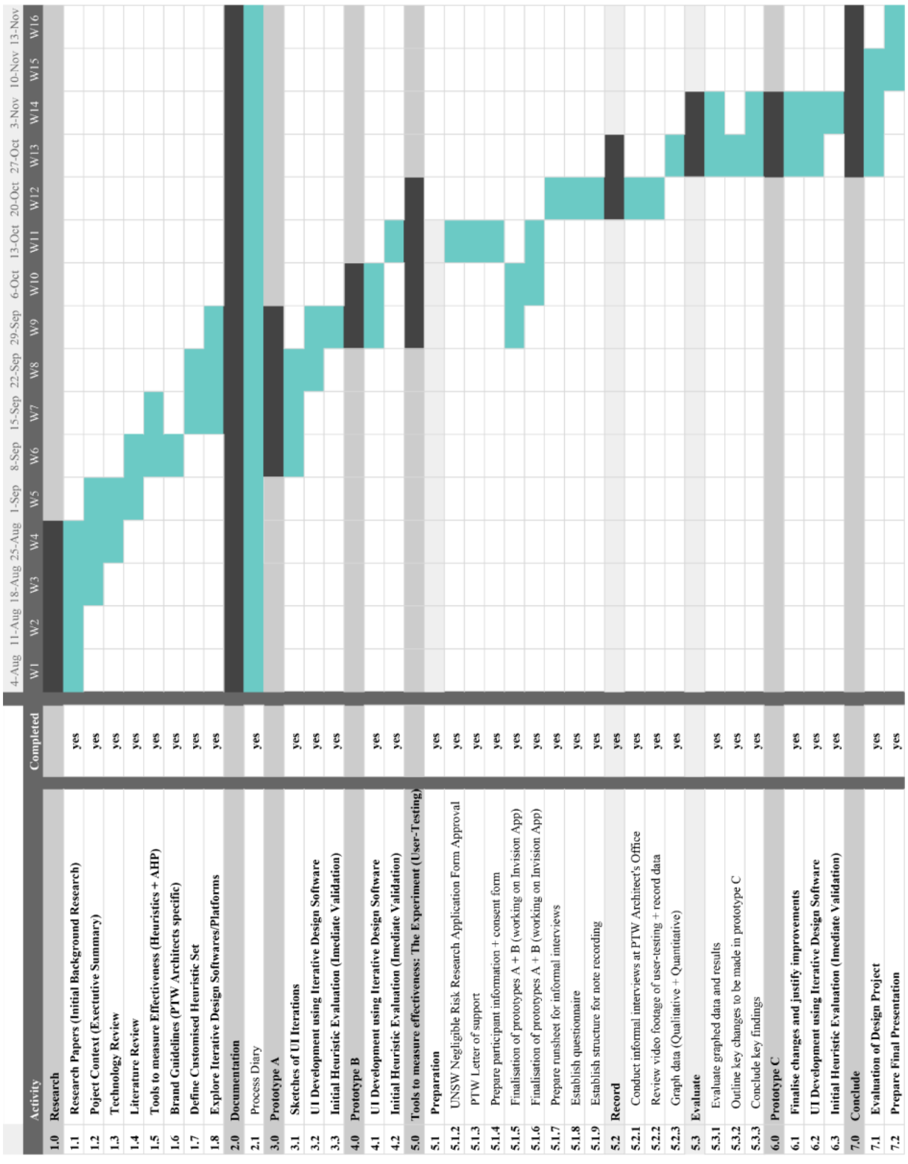


Figure 30. Project Lyrebird: Design project timeline.