Xi'an Jiaotong-Liverpool University
西交利物浦大学

Department of Architecture and Industrial Design

Design Development Process for Communicating Awareness of Climate Change

Weishan Zhang

Thesis submitted
in partial fulfilment of the requirements of
Xi' an Jiaotiong-Liverpool University of
for the degree of
MDes Industrial Design

December 2020

Design Development Process for Communicating Awareness of Climate Change

Abstract

This thesis presents a research-through-design investigation carried out to solve the problem of climate change with a particular interest in interaction design and augmented reality (AR). The purpose of the design project is to communicate awareness of climate change and reduce the alienation between people and environment. Although much research across different fields has been dedicated to addressing climate problems, little has been published to resolve environmental issues through interaction design. The design process of this research follows the Double Diamond Model. In the discovery and definition stage, literature research, secondary research, questionnaires, mainstream user interviews, chart-based analysis, persona, and user journey map are adopted as research methods. In the development and delivery stage, the research methods include rapid prototyping and scenario testing. Two design directions are formed through literature review and user research, which are narrative simulation game based on mobile AR and physical water table based on projected AR. The results of user tests indicate that the latter better answers the research question and achieves the design objectives. This research provides a new perspective for the environmental community to raise public's awareness of climate change.

增强公众对气候变化认知的一系列设计过程

摘要

近年来，诸如澳大利亚山火的自然灾害使越来越多的人意识到全球变暖所带来的危害。许多学者都开始以气候变化为议题展开讨论和研究，但鲜少有人从交互设计角度出发来进行研究。本文尝试以交互设计为手段来引发公众对于气候问题的思考。设计的主要目的是向公众传达环保意识，改善当下人与自然相隔离的现状。设计过程遵循双钻模型。设计方案的探索与确定阶段使用了文献与案例研究、二次研究、问卷调研和图表分析、主流用户访谈、用户画像以及用户旅程图作为研究方法。设计作品的制作和测试阶段使用了快速原型和场景测试作为研究方法。经过文献综述和用户研究后，两个设计方案被确定下来，他们分别是基于手机进行交互的增强现实叙事模拟游戏和基于投影式增强现实和传感器、展示地下水位随天气变化的可交互桌子。用户测试结果表明后者可以更好地回答所研究的问题并达成设计目标。这为如何解决环境问题以及增强公众环保意识提供了一个新的思考方向。

Student name: Weishan Zhang
Student ID number: 1930966
Principal supervisor: Dr. Richard Appleby
Second supervisor: Dr. Thomas Fischer

Document date: December 30, 2020

Acknowledgements

I gratefully acknowledge the generous proofreading support I received from Dr. Mariia and Dr. Aven, whose advice and patience are invaluable to me throughout the year. Meanwhile, I sincerely thank all of the participants in this design research project who took their time from busy schedules to contribute to user research and project evaluation in this design research.

Contents

List of Figures

1 Introduction

1.1 Project Background

This thesis presents a research-through-design investigation in support of addressing the issue of climate change with a particular interest in interaction design and augmented reality (AR). By reviewing a series of problems caused by the Australian wildfire, the author found that it is better to let people discover problems and make their own decisions instead of finding solutions and enforcing them to take actions because environmental issue is a wicked problem. Furthermore, this project allows the user to take spontaneous actions based on their awareness and appreciation of nature. Although many studies have been conducted to address climate issues, little attention has been paid to educate people to raise awareness and appreciation of environment through interaction design. Therefore, the purpose of this research is to review the strategy of interaction design and the interactive technology of AR, to analyse and summarise interactive product and exhibition cases and to identify possible interaction design strategies for communicating awareness of climate change and reducing the alienation between people and environment.

Climate change is a topic that concerns many people and societies from all over the world. Numerous experts believe climate change also includes biodiversity change, ocean acidification and extreme events, such as droughts, floods and wildfire (Sunday, 2020; Christopher *et al.*, 2004; U.S. Global Change Research Program, 2017). A classic example is Australian wildfire in 2019, which burned over 26 million acres of land, destroyed more than 3000 homes, caused at least 30 people and 1 billion animals dead (Hutchins, 2020). Climate experts agree it is almost certain that Australian wildfire results from climate change (Munch, 2020). The temperature in various regions of the world including Australia has continuously risen because of global warming. Last year was the hottest year in Australia, where the average temperature in some areas even reached 48°C in December (Worland and Gunia, 2020). Simultaneously, India Ocean Dipole was at the strongest positive phase for six decades, which led to severe droughts in Australia (Pablo *et al.*, 2019). Such weather conditions inevitably made the fire grow larger and eventually ran out of control. In addition, the consequence of this deadly wildfire is likely to speed up global warming. It not only emitted 400 million tons of carbon dioxide but also caused a large forest reduction that made the carbon sink decrease. The ash produced by the fire even spread to New Zealand and covered the nearby glacier, which accelerated glacial melting.

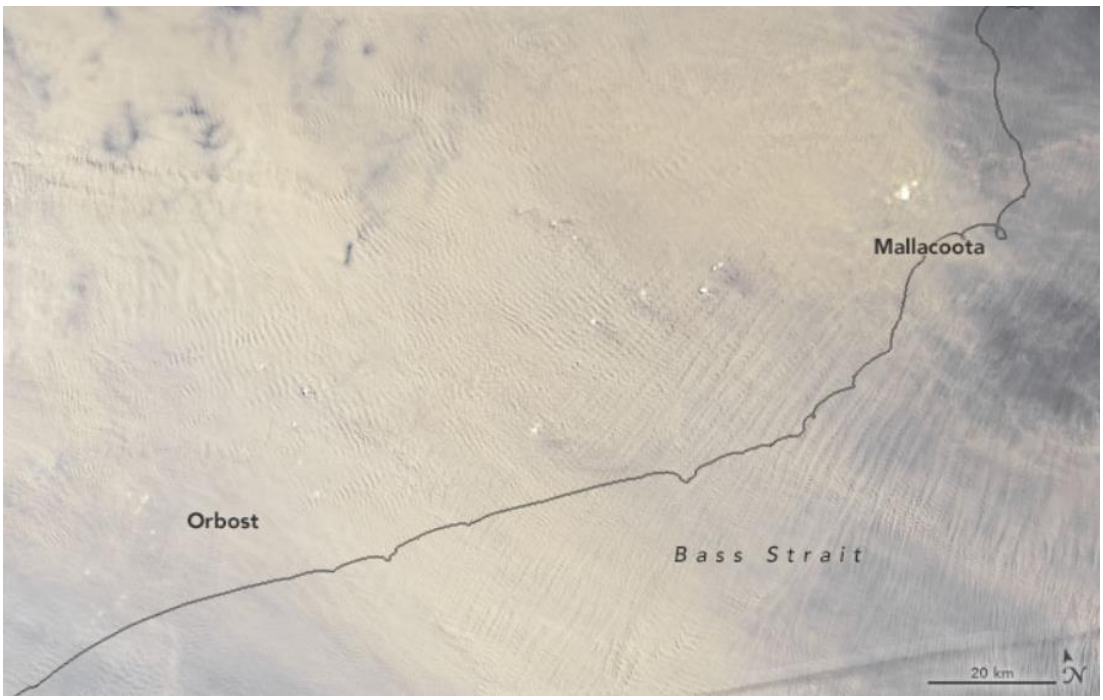


Fig.1.1: A Satellite Photo of the Southeast of Australia, NASA, Jan 2020

In addition to the fire itself, the reactions of local people, enterprises, government, and worldwide media are also worthy of attention. On the one hand, local companies actively participated in refugee rescuing and fire extinguishing operations during the bushfire; on the other hand, continued to mine to produce carbon emissions after the fire. The government's attitude towards global warming has changed several times: At first, they claimed there was no relationship between the wildfire and global warming, and then, they admitted global warming did make the fire difficult to control, but Australia was not responsible for it because they reached their emissions reduction target. However, the fossil fuel industry is a significant contributor to the Australian lifestyle, and the government has been trying to cover up its high emissions record (Judt, 2020). Accordingly, residents began protesting. In December 2019, many people were spontaneously gathering to resist what the government did (Judt, 2020). Media from all over the world were spreading the news to call on everyone to protect the environment. However, with the advent of the rainy season, the fire was extinguished by the forces of nature, the climate protests were prevented by the government, and the events related to wildfire were abandoned by the press.

Apart from wildfire, there were many other disasters in the world during the past year, such as floods, locusts, and hurricanes. The words 'pollution, biological extinction, energy crisis' were mentioned more and more by social media. It can be seen that on the one hand, these disasters made people pay more attention to environmental issues; on the other hand, the efforts we made on protecting the environment are far from enough to slow the pace of climate change. In other words, continuous eco-friendly actions need to be stimulated in another way because people's reflection on environmental issues aroused by such calamities

is always short-lived. Crocker and Lehmann (2013) suggested that spontaneous behaviour is likely to arouse real change. Therefore, this project put the initiative in the hands of users. It lets the user discover problems and decide whether to take action by communicating awareness of environment and reducing people and nature's alienation.

1.2 Literature and Case Study Review

This chapter reviews the research conducted on interaction design, the emerging interactive technology of AR and speculative design. Meanwhile, it includes the cases of mobile AR application, interactive product and interactive AR exhibition. Moreover, the author will use the design principles mentioned in the literature review to evaluate these cases and to find a path for this design project.

1.3 Research Question

This short chapter put forwards the research question addressed in this thesis. Specifically speaking, the central question asks how to educate people to raise awareness and appreciation of nature through interaction design. Two sub-questions are proposed as follow to answer this question. Firstly, what is the interaction to communicate awareness of climate change? Secondly, what is the interaction to reduce the alienation between people and environment?

1.4 Research Method

This chapter mainly discusses the research methods used in this project. They are literature research, secondary research, questionnaires, extreme user interviews, persona, user journey map, rapid prototyping and scenario testing. Through these research methods, the author captures the characteristics of target user, determines the design concepts, and evaluates the prototype.

1.5 Design Process

This chapter describes in detail the design loops of two different interaction design projects. For each design loop, the author conducts user research based on different target user, proposes various design concepts and demonstrates several prototypes. Meanwhile, these two loops answer the research questions step by step. Moreover, this chapter also includes user evaluations for the prototypes.

1.6 Discussions and Conclusions

This chapter restates the objectives of this design project, summarises the context, user research, design concept, design constructs, and user evaluation and discusses the research findings. In addition, it shows how the research and design process influence each other. Finally, it clarifies the limitations of this study and the planning and prospects for further research in the future.

2 Literature and Case Studies Reviews

2.1 Literature

2.1.1 Interaction Design

Interaction design, as a discipline focusing on the interaction between people and products, emerged in the 1980s (Giuseppe and Giancarlo, 2007). Generally speaking, interaction design defines the form of products closely related to user behaviour and product use. It explores the dialogue among products, people, and culture. Therefore, interaction design focuses on user experience in the process of solving design problems (Pirhonen *et al.*, 2005). Cognitive psychology provides basic design principles for interaction design. As is mentioned by Norman (2015, pp.11-36), these principles include 'affordance, signifiers, mapping, feedback and conceptual model'. Affordance shows the relationship between physical objects and people. Signifiers refer to a mark (image or sound) that tells people the correct way to make the product work. Mapping indicates the connection between two things, which is closely related to the context of user. Feedback provides the user with the results of their actions. Affordance, signifiers, mapping and feedback construct conceptual models of a product. The closer the user's conceptual model to the designer's, the more successful the product designs. Therefore, these principles become the criteria for judging an interactive product.

Walter, Kissane and Wang (2014) argued that according to hierarchy of needs theory, individuals' needs are the power to motivate and guide their behaviour and can be divided into five levels: 'physiological needs, safety needs, love and belonging needs, esteem needs and self-actualization needs', which are corresponded to 'functionality, reliability, usability and pleasure' in the context of interaction design. Furthermore, many products only focus on functionality, reliability and usability, while ignoring the factor of pleasure because the low-level needs are the basic requirements for most people and manufacturers have to control costs. However, emotional design advocates that designers should pay attention to the pleasure of a product in the design process to create a better experience for the user, which coincides with the user-centred thinking emphasized by interaction design.

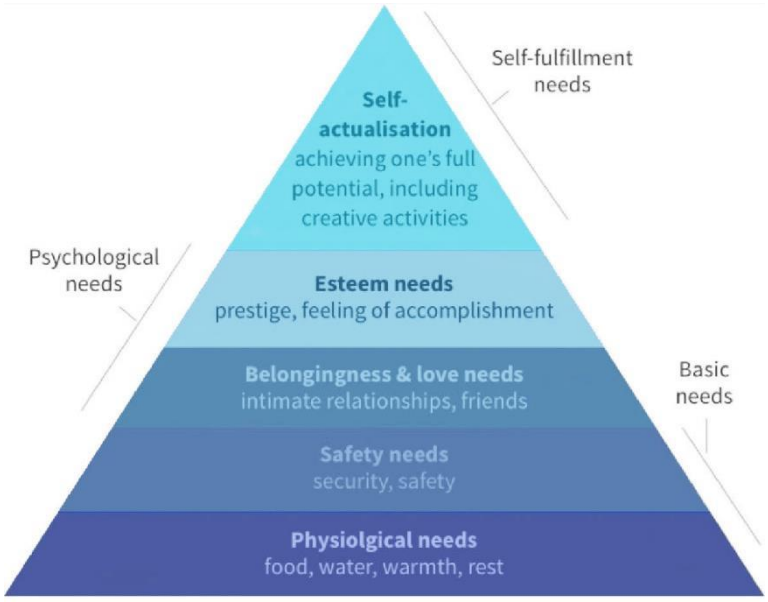


Fig. 2.1: Maslow's hierarchy of needs theory

Emotional design provides instruction to create pleasure in a product. In another book published by Norman (2015, pp.52-85), he suggested that design can be done from three levels: 'instinct, behaviour and reflection'. The instinct level represents the appearance and texture of a product, which determines the product's first impression for the user. The behaviour level represents the function and performance of the product, which determines whether a product is easy to use. The reflection level gives the product meaning beyond its own function, which is closely related to the user's personality, experience and memory. Some top-selling products will sacrifice part of the demand for behaviour level to meet the needs of reflection level. A classic example is Philip Stark's Alien Juicer. Although it is neither easy to use nor durable, it is still popular with consumers because the user's desires to show off and to create talking points are satisfied.

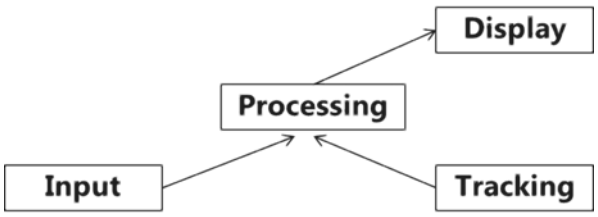
2.1.2 Augmented Reality

Augmented reality (AR) is an interactive technology based on reality where the physical objects are enhanced by computer-generated information (Schueffel, 2017). Azuma (1997) proposed that augmented reality fulfils three basic characteristics: 'a combination of real and virtual worlds, real-time interaction, and accurate 3D registration of virtual and real objects'. In AR, the enhancement of reality is achieved by superimposing digital information on the base map of the physical world, so the user experience is also based on the real environment. In addition, there is a registration relationship between virtual information and the environment, which makes the presentation of virtual information coordinate with changes in time and space in reality to achieve the effect of real-time interaction. Therefore, augmented reality is a technology born from reality, which is different from virtual reality (VR). Sherman and Craig (2019) explained that VR creates a

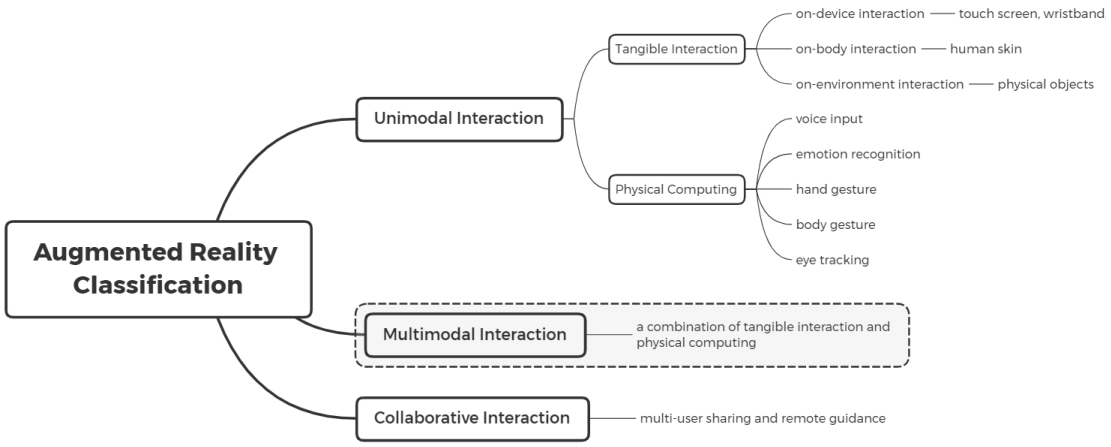
fully synthetic environment where the user's senses are insulated from the real world and immersed in cyberspace. Earlier in 1994, Milgram and Kishino put forward the concept of 'real-virtual unity that clarifies the relationship between virtual reality, augmented reality, and mixed reality'.

Fig, 2.2: Mixed Reality on the Reality-Virtuality Continuum

As an emerging interactive technology, augmented reality system has three components: display; interactive input; viewpoint and objects tracker (Bourguet, 2007). For the reason that the input is closely related to interaction design, this article classifies augmented reality from the perspective of input technology. As is shown in Fig, 2.4, AR can be classified as tangible interaction, physical computing, multimodal interaction and collaborative interaction. Tangible interaction uses physical objects as a medium to interact with users. Physical computing allows the user to interact with digital content without touching the device surface. The above two types belong to single modal interaction that the user interacts with virtual content in single channel. However, multimodal interaction combines different input methods, making the interaction between user and digital world more natural. Collaborative AR interface includes multiple displays to support remote and co-located activities. Microsoft's Hologens is a classic example of collaborative interaction which has the features of multi-user sharing and remote guidance.



Fig, 2.3: Composition of Augmented Reality System



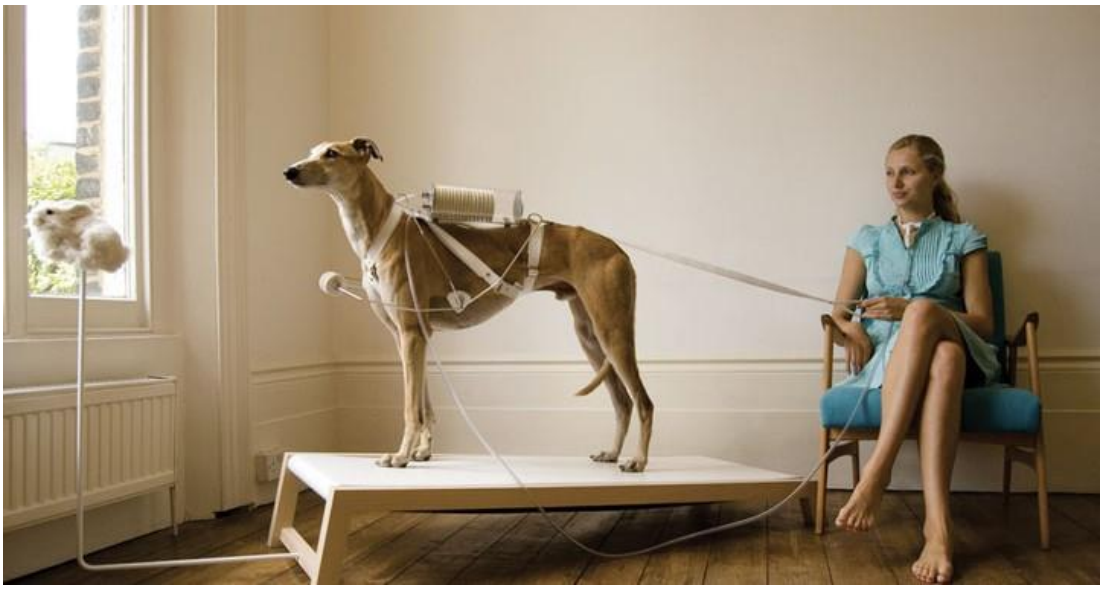
Fig, 2.4: Augmented Reality Classified by Input Technology

Ishii (2008) argued that the objects of tangible user interface act as a bridge between the user and virtual world; it gives the digital content a physical form. The physical products in daily life have their own properties which restrict the way to use them, so linking virtual content with these characteristics can enable users to quickly understand the operating rules of the digital objects. Sharlin *et al.* (2004) suggested that tangible user interface takes advantage of human's innate ability to play with physical objects. Physical computing includes voice input, hand gesture, body gesture and eye tracking. It makes the way of interaction more natural, allowing people to interact visually, auditory, and tactilely. In this project, these two interaction modes will be combined. Research of Nizam *et al.* (2018) found that multimodal interaction is considered as a solution to enhance the interaction between physical and virtual world, and become an ideal interaction technology for AR applications.

2.1.3 Speculative Design

In most situations, design is defined as solving problems. However, Dunne and Raby (2013) proposed that speculative design uses a nonverbal approach – objects to question this basic definition, to give designers a new perspective. In other words, it expresses different opinions by providing alternative design projects. It emphasises that design does not aim to solve every problem but to let people discover problems. Malpass (2015) indicated that speculative design breaks the constraints of shared value or commercial reality, erases the authority that determines what reality is, and believes that establishing reality plural should be the designer's responsibility, which helps the public open their mind. Speculative design comes from critical design but is not equal to critical design (Malpass, 2019). Rather than standing on the opposite side of existing things, speculative design pays more attention to thinking deeply about the situation. Rather than making the user believe in the design project, it focuses more on triggering discussion or even debate.

The goal of speculative design is to inspire people to think actively and to reactivate people's multi-angle understanding and interpretation of reality. It stimulates people's doubts, invites them to use their imagination to think and to outline the future. Therefore, it enables the user to change their behaviour and then to transform reality into an ideal state. Thus, the content of speculative design must be able to attract attention, which is giving unexpected visual impressions to individuals. One well-known example is 'Life Support', in which the designer proposes that commercial animal reproduction for consumption or entertainment can serve as an external organ supplier for humans (Jharrower, 2014). This project uses service animals as future medical equipment to establish a symbiotic relationship with patients, thereby questioning whether it is reasonable for human to treat competition dogs in a current way, and guiding people to think about how humans and animals can have a better relationship.



Fig, 2.5: Life Support by Revital Cohen and Tuur Van Balen Studio

Many design questions refer to the practical problems we encounter in daily life, such as making the chair comfortable. But there are also a large number of social problems, which are the problems appearing in the development of human society, such as limited resources, global warming and population expansion. In such complex situations, it is more important to identify problems than to solve them. The question in this research is climate change which has plagued human beings for decades and has not been effectively solved so far. It is actually a wicked problem that has no ultimate test of a solution (Rittel and Webber, 1973). Therefore, instead of solving it, it is better to let the user discover the problem themselves, which is coincident with the rule of speculative design.

2.2 Case Studies

2.2.1 Reef Diorama and Mobile AR Game

The research works reported in the conference (Alcañiz *et al.*, 2017) show an experimental AR narrative game 'Reef Diorama', where the player can experience the degradation process of the coral reef due to human activities. The game objective is to raise players' awareness of the serious consequences of human activities on the ecological environment of the Great Barrier Reef. As is shown in fig, 2.5, the player can see three-dimensional images of changes in the Great Barrier Reef through mobile phones or tablets. This case shows that game combined with AR can be applied for educating people on environmental issues. In addition, AR technology has two benefits in this project: it makes the virtual subjects more vivid, so that enhances the immersion of narrative game; moreover, it acts as a magic trigger which helps the gamer bring something from the other side of the planet directly in front of your house, so they can start to associate themselves with planetary-scale changes and events.

Fig, 2.6: Narrative AR Game Reef Diorama

Another research reported in that conference (Alcañiz *et al.*, 2017) is also an AR game focusing on environmental protection, namely 'Fred'. Specifically, the goal of this game is to encourage the player to form low-carbon mobility behaviour. It uses Google's API to recognize the modality type of phone owner. When the gamer travels in an environment-friendly way, the game difficulty will be reduced, and rewards will be easily obtained so that the gamer will have a higher score. It can be seen that the principle of such gamification is changing users' habits through the virtual rewards that are connected to the real benefits of low-carbon actions. In addition, Ouariachi, Gutiérrez-Pérez and Olvera-Lobo (2018) proved that games could subtly make teenagers perform environmental behaviour to some extent. However, there are few games focusing on environmental issues in Chinese market, which is exactly a design opportunity.

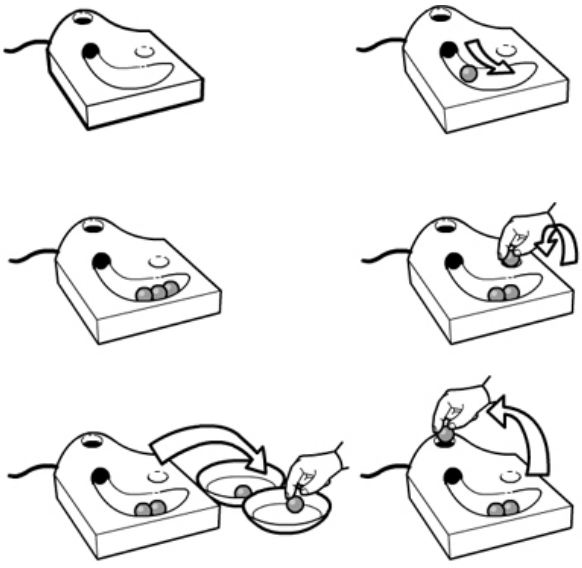
Fig, 2.7: Serious AR Game Fred

2.2.2 Reefs on the Edge and Tangible Interaction

'Reefs on the Edge' is an interactive art installation with a tangible user interface on an exhibition in Australia (Caitilin de Bérigny *et al.*, 2014). This installation is a table using projected AR to show how climate change affects the underwater ecosystem of the Great Barrier Reef. As is shown in Fig, 2.8, the hemispherical objects on the table represent corals, and the user can experience the impact of climate change on coral spawning by controlling these physical objects. The AR content demonstrates the effect of coral status with changes in ocean temperature and acidity by altering colour. In this project, the AR content acts as an affordance, and the hemispherical objects work as signifiers (see Section 2.1.1). It indicates that the connection of physical objects and virtual content in the tangible user interface allows users to quickly understand how to interact with the installation and to be engaged easily. Therefore, the combination of projected AR and tangible interaction can be a significant way to support environmental education and to raise awareness of climate change.

Fig, 2.8: onacloV's Reefs on the Edge

Another example of tangible interaction is 'Marble Answering Machine' by Durrell Bishop, which is considered as one of the earliest tangible interaction design (Jansen, 2014). Every time a voice message is recorded, the machine spits out a marble whose order represents the order of the arrived message. The user can play the record by putting the marble in a small dent. There are many small plates with names beside the machine to store the marbles for different people. The point about this answering machine is that each marble had a unique fingerprint that could not be duplicated exactly. In this case, the marble act as a trigger to previous experiences, which makes the voice message tangible. Therefore, it is a design opportunity to convey emotional impressions in physical objects to build awareness of climate change.



Fig, 2.8: Durrell Bishop's Marble Answering Machine

2.2.3 Fires of Change and Exhibition

'Fires of Change' is a cooperative art exhibition where the history of the American fire regimes changing with climate change is shown through multimedia art installation (Colavito *et al.*, 2020). The results of the survey of exhibition visitors demonstrate that viewing such exhibition can give individuals a deeper understanding of how climate change impacts on fire policies and make citizens more supportive of the government decision. In other words, explaining scientific knowledge in an artistic way can change people's attitude towards environmental issues. In addition, the curators from different fields form an eco-friendly community through the exhibition. Therefore, it can be conclusively shown that design or art exhibition is an effective way to deal with complex ecological problems because it let viewers discover the problems themselves.

Fig, 2.9: Fires of Change Exhibition

This conclusion is in line with the philosophy of speculative design (see Section 2.1.3). Different from problem-solving design, speculative design creates an opportunity to stimulate follow-up discussions on specific issues. It can be considered as a design activity in which designers express their attitudes through their projects, and users respond and get insights from it. Meanwhile, the representation of speculative design is diverse, including product prototypes, interactive installations, photography, graphic works and performance art. Therefore, speculative design projects are always displayed in the form of exhibitions.

2.3 Summary

The literature and cases provide different ideas for the following design work. The first option is the AR game based on mobile technology, whose interaction is two-dimensional and screen-based. It encourages users to discover problems and to form low-carbon behaviours by engaging them in climate change stories and giving some virtual or even physical benefits. The other option is a projected AR interactive installation, which is usually presented in exhibitions. The interaction of the installation is multi-modal and based on tangible objects. It shows users the impact of climate change on the environment in an abstract way to guide users to discover problems, and then to take actions spontaneously. In the subsequent design process, the author will design with two ideas separately, compare them through user testing, and analyse which is the better answer to the research question.

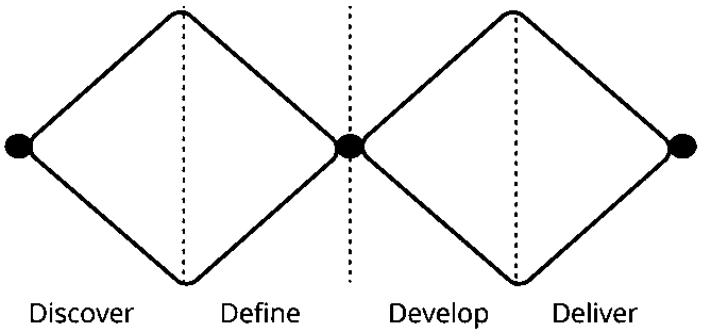
3 Research Question

The central question of this study asks how to educate people to raise awareness and appreciation of environment through interaction design. To answer this question, two sub-questions are proposed as follow. Firstly, how to communicate awareness of climate change? Secondly, how to reduce the alienation between people and environment?

4 Research Method

4.1 Introduction

The design process of this research follows 'the Double Diamond Model'. This design model encompasses the stage of discovery and definition (the first diamond) and the stage of development and delivery (the second diamond). In the first stage, the designers' job is to understand the user's needs by getting the data from users and filter the irrelevant information so that a clear plan for dealing with the research problems can be formed. In the second stage, the designer will make some prototypes to make the solution into reality. Although it sounds like a linear process, it actually works in a circular way (Design Council. 2015).



Fig, 4.1: Double Diamond Model

Therefore, this chapter will introduce the research methods used in these two stages, respectively. To sum up, the research methods include literature research, secondary research, questionnaires, mainstream user interviews, chart-based analysis, persona, user journey map, rapid prototyping and scenario testing. Through these research methods, the author captures the characteristics of target user, determines the design concepts, and evaluates the prototype. The following chart shows the research framework of the thesis.

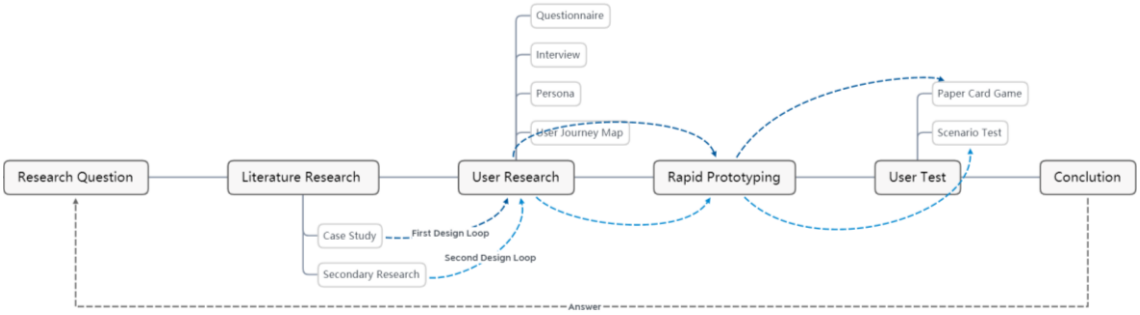


Fig.1.2: The Chart of Research Through Design

4.2 Discovery and Definition Stage

In the very first stage, the author investigates the related literature and cases of interaction design, AR interaction technology and speculative design, to extract a few principles of interaction design and two potential design directions to guide the following design work. During the first round of design — the AR mobile game, face-to-face interviews are restricted due to the impact of the coronavirus epidemic, so only questionnaires are used to conduct user research. The questions in the survey involve basic information of user (such as age, income and education) and their views on environmental protection and gaming. Afterwards, the author analyses and summarises the results of questionnaire using quantitative charts and persona to reveal pain points. Persona helps designers to think in user's position, which makes the product closer to the user (Brown and Kātz, 2011, pp.108). Moreover, some possible behaviour that is not environmental friendly in daily life is discovered as design opportunities through the user journey map.

In the second round of design — the AR interactive installation in exhibition, the author first analyses the defects in the first round of design and brainstorms to find possible design solutions. However, it is found that these proposals lack a context. Therefore, secondary research is essential under this circumstance. Secondary research can help designers understand the background more targeted and obtain the latest information in relevant fields, which can inspire designers to create their ideas (*Secondary Research,* no date). In the secondary research, the author discovers that the water table is a worthy direction (suggested by second supervisor Thomas) because a great number of people know little about it. Moreover, the table in this vocabulary can be regarded as the physical table and connected to the interactive table case (see Section 2.2.2). Thus, the water table is determined as design theme. In the other half of secondary research, the author analyses the usage scenario of different tables to establish the context. Afterwards, user research is conducted through combined methods of quantitative and qualitative research that is questionnaires and mainstream user interviews. The questions in the questionnaire involve the user's basic information and their opinions on groundwater level and exhibition, whose results are analysed and summarised by charts and persona. Furthermore, the difference between the ordinary purchase process of goods and the purchase process of exhibition souvenirs is compared through the user journey map. Finally, a conclusion can be drawn that the project should be divided into two product lines: exhibition products and domestic products.

In this research, part of the questionnaire will use the Likert scale to quantitatively measure the data. Krzych *et al.* (2018) pointed out that the Likert scale can be integrated with questionnaires to get a more reliable result. Moreover, the interview will be designed to be partly structured to get hidden needs. Zablith and Osman (2019) analysed unstructured reviews by proposing a novel predictive analytics framework, which indicates unstructured

reviews contribute to uncovering the insights that were not discovered by closed-ended questionnaires. This might be adapted to user interviews as well.

4.3 Development and Delivery Stage

In the design of AR game, the author first summarises the design concept. The subsequent design process follows the rapid prototyping method, which is making different kinds of simple prototypes to verify the feasibility of an idea (*Rapid Prototyping*, no date). Specifically, the game background story video and high-fidelity interactive interfaced are made by spark AR studio and Adobe XD separately and tested by me to be improved. And then modified paper models and a game demo video are made for user testing. DAU CardSim is a card game based on multiplayer scenarios, designed to enhance acquisition skills and teamwork. One way to create prototypes during the design process in this game is to assemble various paper models. By using paper substitutes as system components, the developing team and any incoming external testers can perform usability tests and quickly modify it (Cannon-Bowers and Bowers, 2010, pp81-101). Therefore, the paper prototype in this project can be regarded as a simple card game, which allows gamer to better understand game rules and participate in game. The demo video shows the user the design context and art style of game, which can be regarded as a scenario testing.

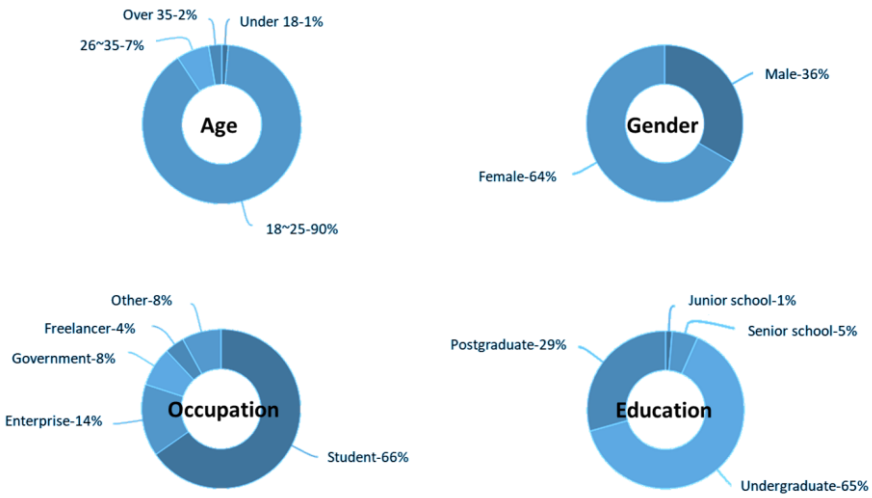
In the design process of water table, the author adapts the rapid prototyping method as well. After drawing a few sketches, the models are made and iterated in four versions, which consists of foam model, wood model, 3D printed model, and final interactive model. The user test of these models only includes their perception of appearance because the models are not full scale. Therefore, scenario testing is required for further user testing. Scenario testing is to inform users of the possible context and the value of the design concept by showing images of usage scenario for the user. In this project, the author made two demo videos for scenario testing, which not only demonstrates the context but also presents how the table interacts with people and environment.

5 Design Process

5.1 The AR Mobile Game

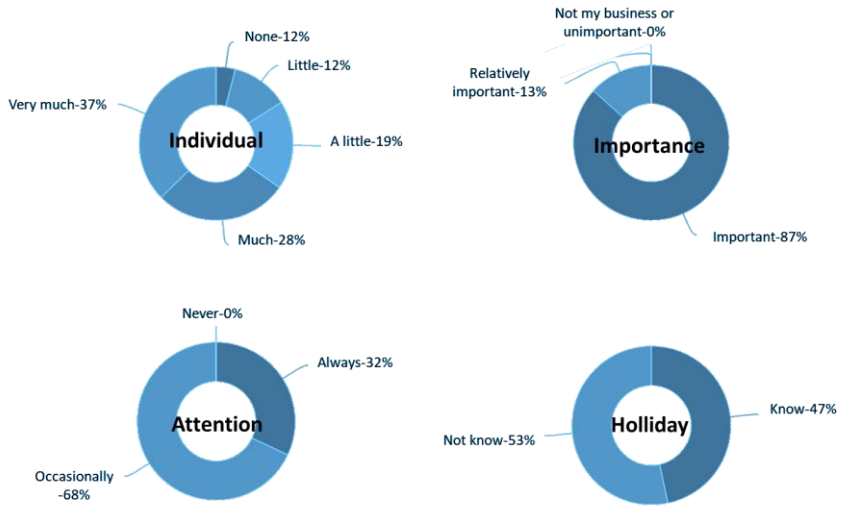
5.1.1 User Research

The first section is questionnaire, which is divided into three sections: personal information, question about environment protecting, question about mobile game. There are 145 people participating in this survey, and 104 of them answer the questions about mobile game. The results of questionnaire are analysed through the following quantitative charts. As is shown in Fig, 5.1, most of the participants are students between 18-25 years old with a bachelor degree or above.



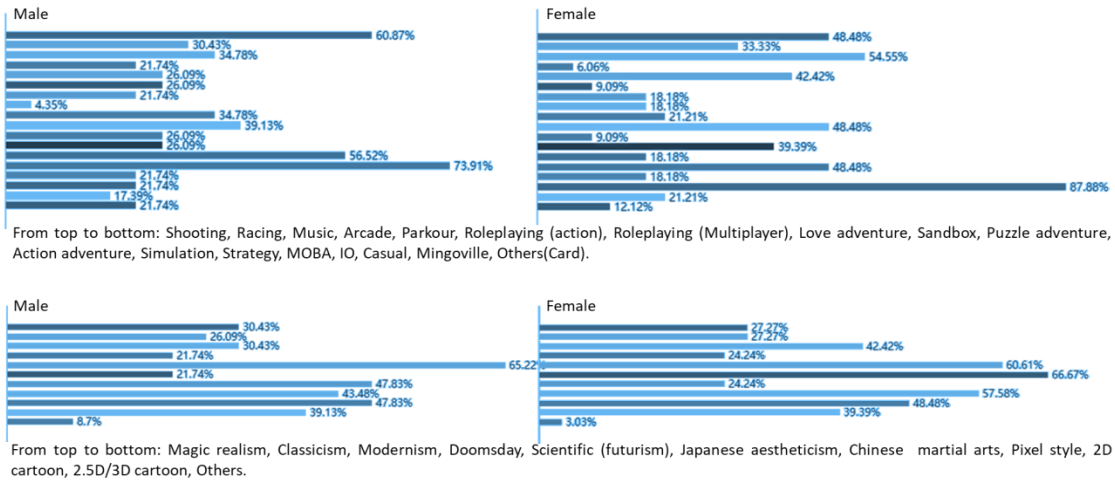
Fig, 5.1: Questionnaire: Basic Information

In addition, according to Fig, 5.2, they believe protecting environment is quite important and individuals can play a significant role in it. However, they are not willing to spend much time and energy on it. Over half of the people have little knowledge and experience of protecting environment because of the lack of environmental awareness which is a design opportunity.



Fig, 5.2: Questionnaire: Attitudes to Environmental Issues

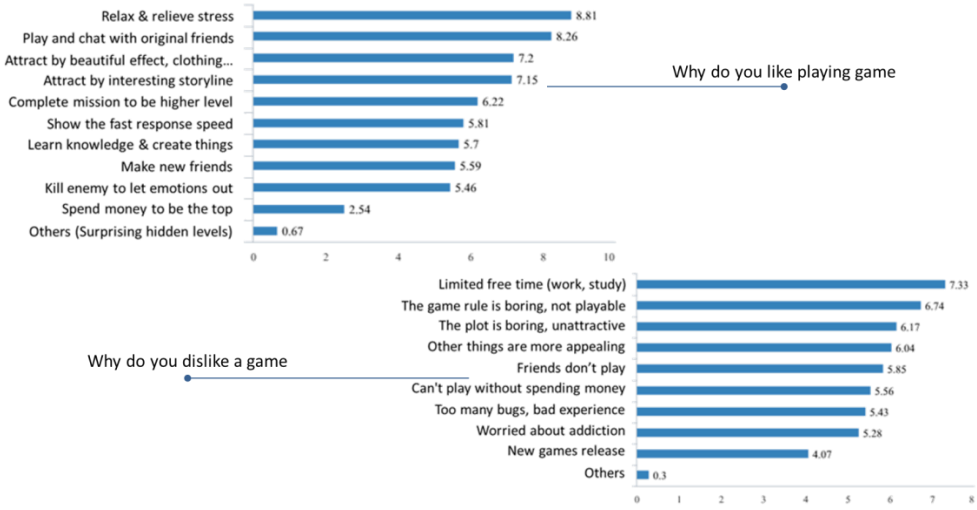
In terms of mobile games, it is manifest from Fig, 5.3 that different genders have different preferences. Compared with women, a larger percentage of men tend to play games every day and spend money on games. With regards to the type and art style of game, the female gamer prefers casual game and music game, with Japanese aestheticism, futurism or pixel art style. In contrast, the male gamer prefers multiplayer online battle arena game, shooting game and classic strategy game with futurism or Chinese martial art style. Therefore, the game design should focus on single-gender or choose a popular style that almost nobody dislikes, such as puzzle adventure game or sandbox game.



Fig, 5.3: Questionnaire: Game Preference of Different Gender

It can be seen from Fig, 5.4 that a game attracts players mainly through three aspects: interesting game rules, attractive plots and targeted social functions, which should be focus points during design process. Under the context of today's increasingly fast-paced life, the duration of a round of game should not be too long. The game should be designed to be

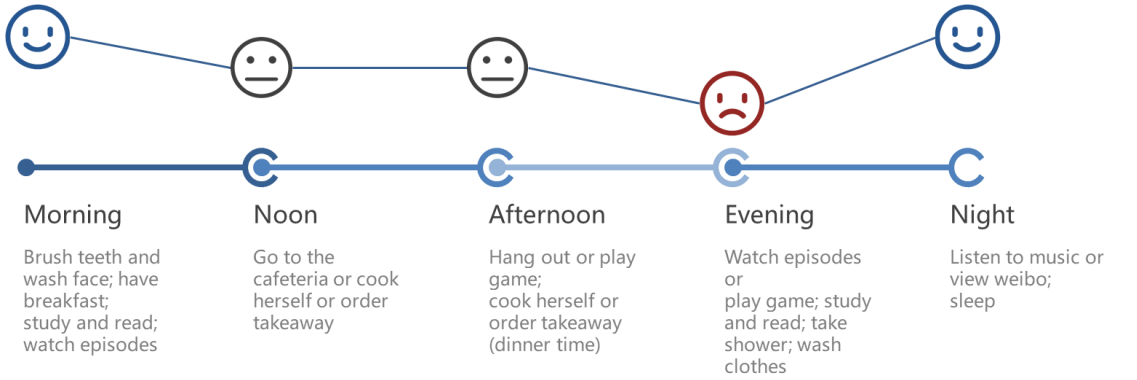
able to play in a fragmented time with a relaxed rhythm. The last question is, what are the positive effects of playing games. It is an open-ended question, and the result indicates mobile games do have the power to change people's minds and behaviours, which confirms it is feasible to raise individuals' awareness of climate change in the form of game.



Fig, 5.4: Questionnaire: Game Impact

Therefore, the persona is a female gamer named Amy, who is the Z generation and has a bachelor degree. Game is an essential part of her life. She spends most of her free time playing games at home because she believes playing with friends can root friendship. Her favourite game types are simulation game and puzzle adventure game, with a Japanese aestheticism or futurism art style. The obstacles she faces are limited leisure time and the desire to socialize through games. Additionally, she barely notices information on climate change and eco-friendly activities for the reason that protecting environment is important but not necessary to her.

Moreover, some possible behaviour that is not eco-friendly in Amy's daily life is discovered as design opportunities through the user journey map. Fig, 5.5 demonstrates what she usually does at home during vacation or weekends. The pain points focus on her actions that possibly cause damage to the environment. And these actions should be changed in the game. For example, the takeaway will use disposable tableware; cooking waste and household waste are mixed together and are not classified; electric waste might be produced by forgetting to unplug the electrical appliance and leaving the lights open; water may be wasted in cooking, bathing and clothes washing process.



Fig, 5.5: User Journey Map

In summary, there are four problems needed to be noted in the game design process. Firstly, people barely pay attention to protect environment because they don't know and can't see the benefits. Secondly, as a result of the limited awareness of climate issues, some behaviour is not eco-friendly in people's daily life. Thirdly, under the context of today's increasingly fast-paced life, a game should be interesting but not consume much time. Lastly, most social activities of the gamers happen in the game so that they like to stay at home.

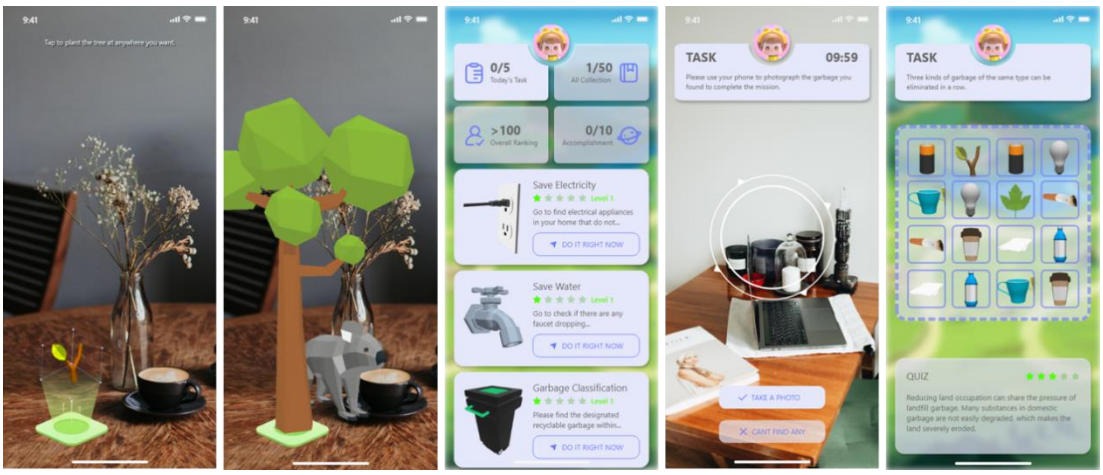
5.1.2 Rapid Prototyping

Therefore, the design concept is a narrative simulation AR game where Z generation female is the mainstream player. Beginning of the story is Australian wildfire, but the game gives players the ability to change this 'tragedy' into 'comedy'. The main purpose is to raise players' awareness of environment. At the beginning stage, game tasks are simple environmental actions that can be completed at home during fragmented time. After the task is completed, there will be virtual or physical rewards. Some tasks are combined with puzzle games to bring more fun. Co-planting and group competition will be set in the game to meet the social needs of player. Tab, 5.1 explains the design concept more thoroughly.

Tab, 5.1: Design Concept

	Beginner period	Growth period	Platform period
Main purpose	1. Familiar with the game, rapid growth 2. Expand the social circle and conduct social guidance	1. Maintain the growth of the character base. 2. Player ability verification. 3. Promote deep socialization and form a fixed team.	1. Player ability verification to maintain the normal circulation of game currency. 2. Strengthen social relationships.
Single play mode	1. Daily: Cultivate plants and animals, get new species, in-game currency and upgrades. Meet friends and help each other. ——Only indoor tasks, save water and electricity, and sort waste. 2. Activities: There are bonus rewards for logging into the game during the environmental festival.	1. Daily: Speed up player upgrades to ensure that new players quickly catch up with mainstream players. ——Start outdoor missions, low-carbon transport, bring your own cup and shopping bag when you go out, and exchange idle items 2. Activities: Offline activities during the festival. ——Open the achievement system.	Personalized design system to design your own forest.
Team play mode	1. Daily visits to help watering and fertilization or destruction. 2. Build relationships with friends and get special rewards for planting together.	Turn on the team mode; team tasks promote interaction between members.	Community exchange platform to share environmental protection experience and game experience.
Competitive play mode	1. Rank of plants and animals, number ranking. 2. Quiz competes with strangers.	1. Start team competition and fix team awareness. 2. Turn on time-limited rewards and compete for resources.	Strengthen communication internally and strengthen competition externally.

The game background story video and high-fidelity interface are made by spark AR studio and Adobe XD respectively and tested by the author. As is shown in Fig, 5.6, the player will nurture plants and encounter animals in the game, and these creatures are the virtual rewards. The middle page is the home module including everyday tasks, collection, ranking and accomplishment. The mission can be divided into two categories: tasks completed by photo verification to ensure the user indeed implement low-carbon actions in reality; tasks completed by solving puzzles to educate the user about environmental protection and raise their awareness of climate change.



Fig, 5.6: Prototype

5.1.3 Paper Prototype and User Test

Paper prototypes and a modified game demo video are made for user testing. The demo video shows the user the design context and art style of game, which can be considered as a scenario testing. The paper prototype in this project can be regarded as a simple card game. The following images only include part of the cards. According to Fig, 5.7, the first kind of card is creature card with blue border. During the planting process, user needs to complete tasks to ensure the plant is in a healthy state; otherwise the growth rate will slow down. Plants of different levels are classified according to the rarity of plants in real life. The higher the level, the more difficult it is to obtain, so as the animals. Planting with friends can acquire special plants and animals.

Fig, 5.7: Prototype

It can be seen from Fig, 5.8 that the second kind of card is skill and accomplishment card with green border. The nutrients for plant growth are obtained by put low-carbon actions into practice in daily life. Different environmental actions have different benefits and lead to different supplement accordingly. Food and medicine to feed animals are obtained by

participating in puzzle tasks. The currency is obtained by completing tasks or charge in game, which can buy anything. The player will obtain medals when having a reward in reality.

Fig, 5.8: Prototype

Fig, 5.9 presents the third kind of card that is event card with red border. Whenever a natural disaster occurs in real life, the game world will also be affected to a certain extent. Players can eliminate disasters by completing missions within the required time, and failure will cause negative influence. Teamwork and making friends obtain special rewards and enhance the positive effect.

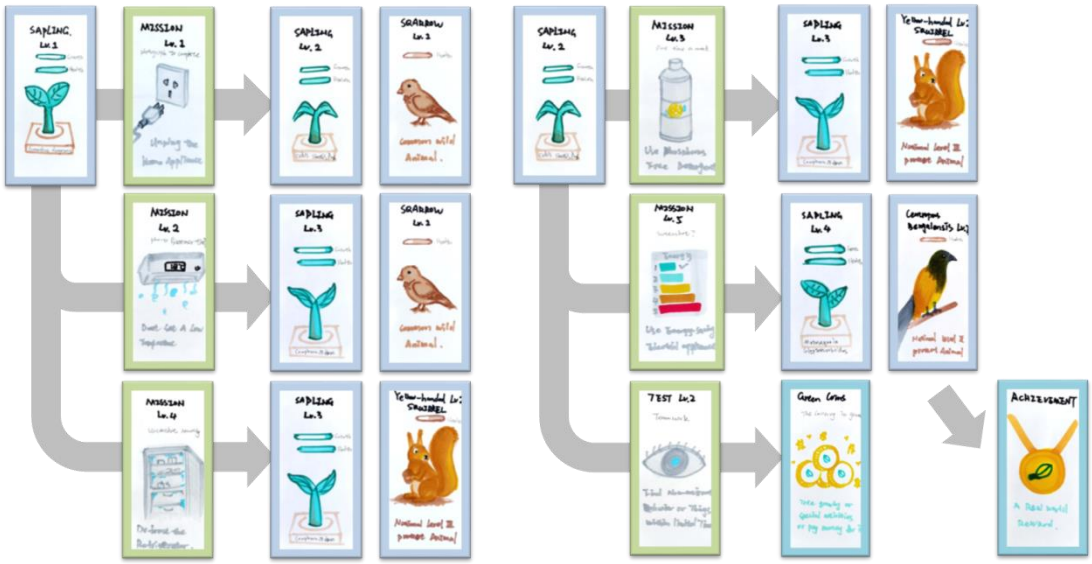
Fig, 5.9: Prototype

The fourth kind of card is mission card with red border (see Fig, 5.10). Tasks are divided into five levels, and part of them provides an opportunity to collaborate with the products manufactures. The game can bring costumers to their shop, and they can fund for the real-life rewards in the game, or just make their products into rewards. Level 1 tasks are the easiest to complete, including unplugging appliances, closing water taps and finding recyclable garbage. Level 2 tasks include setting a higher temperature for air conditioner, setting a lower temperature for the water heater, not ordering takeaways, and not using

disposable tableware. Level 3 tasks include setting to low water mode when washing clothes and using phosphorus-free detergent. Level 4 tasks include defrosting the refrigerator and tying a rubber band to the faucet to control water consumption. Level 5 tasks require users to purchase environmentally friendly products, such as solar water heater, water-saving toilet and energy-saving appliance. Puzzle-type missions require players to participate in groups. Two teams compete with each other; team wins only when everyone in the team passes the test.

Fig, 5.10: Prototype

It is manifesting from Fig, 5.11 that completing different missions lead to various outcomes. When the player reaches the specified level in the game, they can plant real trees or participate in animals rescue activities in reality to obtain achievement medals. The location of tree planting and animal rescue activities can be set in certain touring spots. The game brings passenger flow to the spots, and the spots provide the materials needed for the activities.



Fig, 5.11: Logical Diagram

In this user test, four female players are invited to experience the game. In the face-to-face interview after playing, two users indicated that the rules and modes of the game are very interesting, and they are willing to play such games. The other two users believed that some missions in the game are unreasonable because it may violate their privacy to take photos to ensure that they have implemented low-carbon behaviours in real life. Moreover, one player proposed that the task that induces players to buy eco-friendly products may be illegal in China. When it comes to whether the game achieves its purpose, one player thought the game significantly improves her awareness of environment. Two users believed that the game raises their awareness of climate change to a certain extent. One indicated that she might not play it from the beginning because this is not the type of game she loves to play. However, she also mentioned that a feature in game reduces the alienation between people and environment, which is the growth of plants will be affected by natural disasters in reality. In addition, the author's tutor Richard and Thomas proposed that there are two basic contradictions in this project. Firstly, environment protection requires an appreciation of nature, but mobile games alienate users from natural environment. Secondly, protecting the environment is a long-term action, but people can't always play games. Thus, the second round of design — projected AR installation goes into operation.

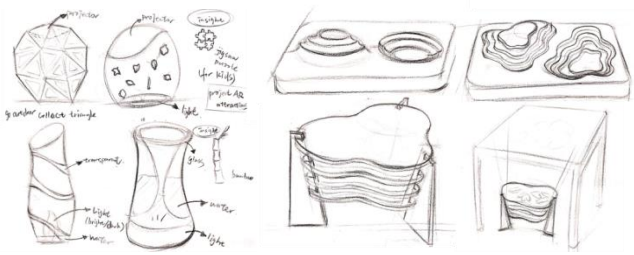
5.2 The Water Table

5.2.1 Brainstorm and Secondary Research

Before the secondary research, the author first brainstorms many design schemes. As is shown in Fig, 5.12, the first version is basically game supporting products which include jewellery that projects AR game and an interactive painting (water box). The jewellery links digital game and real world. The painting shows changes in the indoor environment, which acts as a trigger to build awareness of environment and conveys emotional impressions. However, these are basically two-dimensional representations.

Fig, 5.12: First Version of Design

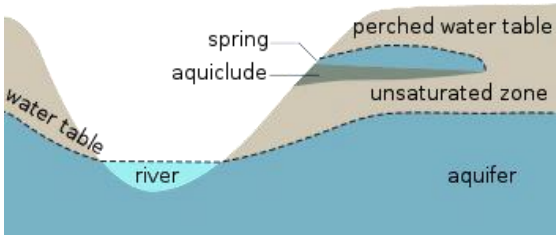
Therefore, the second version (left side of Fig, 5.13) is a water flow object with a light that operates in an abstract way according to environmental conditions in other places. Specifically, it shows temperature and air quality through the water level and the intensity of light. However, this water lamp is not an interaction design project because it cannot interact with people, and the communication of information is vague. Thus, the author starts to find the linking activity. Some people love playing jigsaw puzzle on the table during childhood. So the third version (bottom right of Fig, 5.13) is a table with a transparent desktop under which there will be a projector projecting natural scenes, puzzle patterns and weather conditions. Children first collect leaves at the projected spot, then place them according to the projected visual cues to create a shadow pattern. However, the design work only conveys one message of environment— the weather, which is too weak to raise awareness and appreciation of climate change. Moreover, the whole project lacks context so that the target user cannot be defined clearly. Last but not least, the interaction of game is ambiguous and complicated, which makes it hard to follow the principles of interaction design (see Section 2.1.1). Therefore, secondary research is necessary.



Fig, 5.13: Second and Third Version of Design

Groundwater is the water stored in the zone of saturation where the soil and rocks are saturated with water. It is an important source of water for human life, production and ecology and closely related to climate change. The source of groundwater mainly comes from the infiltration of surface water. It can be seen from Fig 5.14, the water table is the surface level of groundwater. It is declining year by year because of climate change (Graham, 2019). One reason is that some areas suffer from drought and residents' demand for water increase due to global warming, so groundwater supplementation is insufficient. Furthermore, the growth of temperature increase soil evaporation capacity and vegetation transpiration capacity, so the consumption of groundwater evapotranspiration goes up. Moreover, climate change increases the occurrence of extreme weather, and short-term rapid precipitation has a very limited supplementation. Especially for coastal cities, the seawater-freshwater line moves inland as precipitation recharges decrease and sea level rises, which decreases the availability of fresh water. Although the decline of water table is detrimental to humanity, excessive water table also causes adverse effects. For example, in the Jiangsu, Zhejiang and Shanghai regions of China, the annual summer rainfall is very abundant leading to a soaring water table, which brings the salt of soil into freshwater and

affects water quality (*Water Sources in Shanghai,* 2010). Meanwhile, the excessively high water table will also affect the foundation of buildings.



Fig, 5.14: Water Table

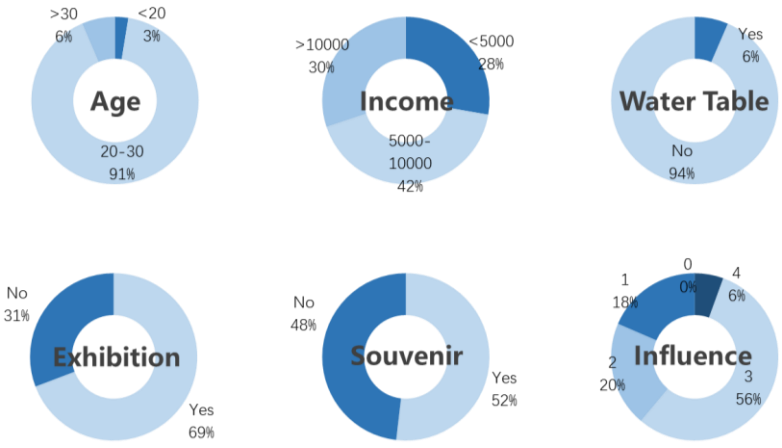
As the impact of climate change on groundwater resources is becoming more and more obvious, the increasingly prominent water use contradiction forces us to pay more attention to the impact of climate change on groundwater. However, people rarely notice it because the groundwater is hidden deep in the ground under our feet. Therefore, it is a design opportunity to create a real water table to increase people's awareness of groundwater and climate change. Next question should be figured out is people usually use table in what situation. Chinese people love to invite guests home (Fig, 5.15). The host and guests will sit around the side table having a cup of tea or snacks. It is a classic social scenario which is suitable to communicate awareness of climate change. Moreover, it is quite common recently for young people in first-tier city to see interactive AR exhibitions. In such exhibition, interactive AR table is used to spread the concept of environmental protection (see Section 2.2.2).

Fig, 5.15: Chinese hospitality

5.2.2 User Research

The first section is a questionnaire that contains only six questions. There are 78 people participating in this survey, 54 of whom answer the questions about exhibition. As is shown in Fig, 5.16, most of the participants are individuals between 20-30 years old, with over 5000 RMB salary or living expenses. Most people do not know climate change has an effect on the water table and always go to exhibitions in leisure time. For those who often see exhibitions, over half of them will buy souvenirs after the exhibition. The influence of

the exhibition on their mind is measured quantitatively by the Likert scale, and larger value represents a greater impact. The result indicates that exhibition will affect people's perceptions to a certain extent.



Fig, 5.16: Chinese hospitality

In addition, mainstream user interview is conducted to get more information. The first interviewee is Bodong, a 28 years old worker with over 20000 RMB salaries. He enjoys travelling, exercising and seeing exhibitions in free time. He said he would buy exhibition souvenirs even it is expensive. The second interviewee is Wen, a 24 years old student. She is also a well-known blogger who is willing to share her life on social network and loves to have parties with friends. The products she posted will become a must-buy or must-see for her fans. The last interviewee is Xinyi, a 26 years old designer living in Shanghai. She likes to go to interactive exhibitions to receive inspiration and to share the photography taken in the exhibition on social media. She also said she prefers to buy eco-friendly products than ordinary one. They all know little information about the water table.

Therefore, the persona is a yuppie named Judy. She lives in first-tier city with over 10000 RMB incomes. She is a full-time designer and part-time blogger. She goes to see exhibitions every weekend and sometimes buys souvenirs. Sharing is an essential part of her life, so inviting friends to be guests or to party at home is a way of rooting friendship for her. She loves photography and is willing to share photos on social network. However, she has limited access to the information on climate change, and so do her friends. She will be influenced by the taste of her own, her friends and other designers.

Moreover, the differences between the conventional goods purchase process and the exhibition souvenirs purchase process in Judy's life is compared through the user journey map. According to Fig, 5.5, she usually shops online, during which she first sees the advertisement and user comments on the product, and then decides whether to buy it. She always finds it boring and troublesome to see advertisement and read reviews. After buying and using the products, she will make comments on the sopping website. However, in the

other process, she can go to the exhibition and interact with the exhibits first and then decide whether to buy the souvenir. Moreover, the souvenir can trigger her memory about the exhibition when she sees or uses it, and this will stimulate her to share her experience and the souvenir itself on social media, so that more people will know the message conveyed by the exhibition. Therefore, a conclusion can be drawn that this project should be divided into two product lines: exhibition products and domestic products.

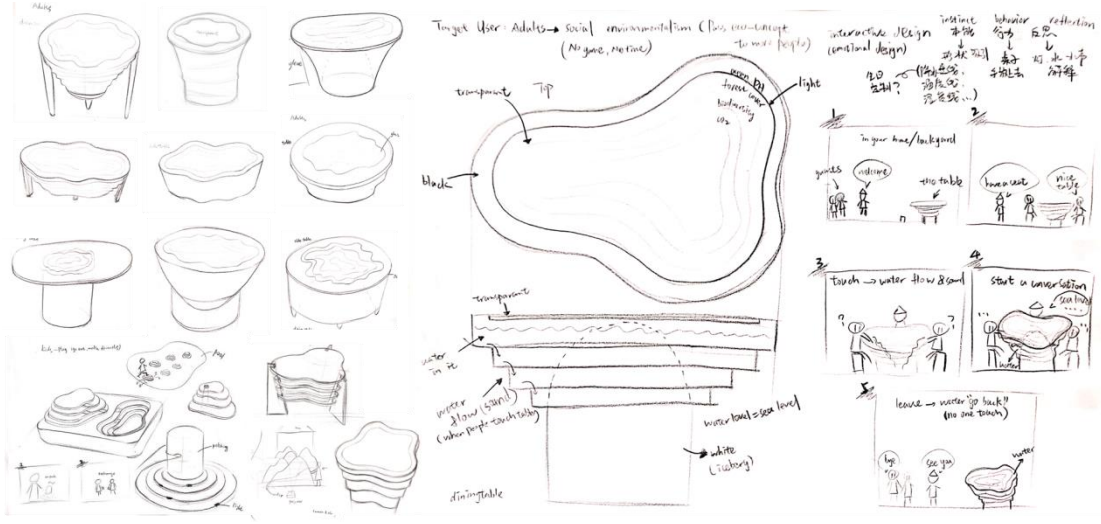
Fig, 5.17: User Journey Map

5.2.3 Rapid Prototype

The water table has two product lines. One line is a multi-person interactive table for exhibition use. It uses projection AR as an interaction method. The AR content conveys awareness of water table and climate change. The other line is a side table for family, which is a simplified and minified version of the exhibition table. It uses the water inside it to reflect the change of real water table with local weather. When the weather is normal, the water level in the table is equal to the average water table of the year. When encountering extreme weather, the water level will change exaggeratedly. For example, drought will lower the water level, and heavy rain will raise the water level. Moreover, the water inside will float when users put their hands or cups on it. This table can be sold as ordinary furniture or as exhibition souvenir.

The following design works will focus on the family side table. As is shown in the right side of Fig, 5.18, when the user invites guests home, they will sit around the water table. The water inside starts flowing when guests touch the table, which starts a conversation about real water table and climate change. From the perspective of emotional design (see Section 2.1.1), the appearance of table should be unique, so that users will be attracted by it from

instinct level. From behaviour level, when sitting beside the table, people will naturally place their hands on it to trigger interaction. From reflection level, the water level and water flow will stimulate discussions on climate change.



Fig, 5.18: Sketches of Family Side Table

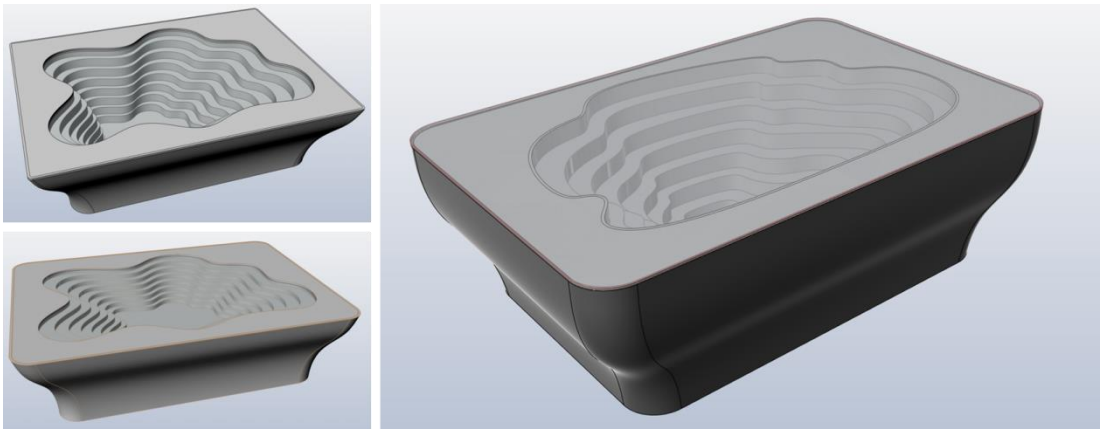
And then three foam models are created by foam board, double-sided tape and scotch tape. As is shown in Fig, 5.19, the scotch tape represents the transparent desktop. The model scale is 1:4. However, it is no contrast to shape both the inside and outside of table into contour lines, so it is modified in the next group of models.

Fig, 5.19: Foam Models

It can be seen from Fig, 5.20, more accurate wood models are produced using medium-density fibreboard (MDF) and polyvinyl chloride board (PVC). The method to make them is first drawing a CAD model, then using computer numerical control machining (CNC) to cut MDF and using laser engraving to cut PVC. The model scale is 1:4. As Richard suggested, the inner shape of table is similar to contour lines, which represents the natural world, while the outer shape is a square represents the artificial world. Thus, the shape of the entire table implies the connection between human and nature. The final model will be modified based on the figure's right side due to the need to store water.

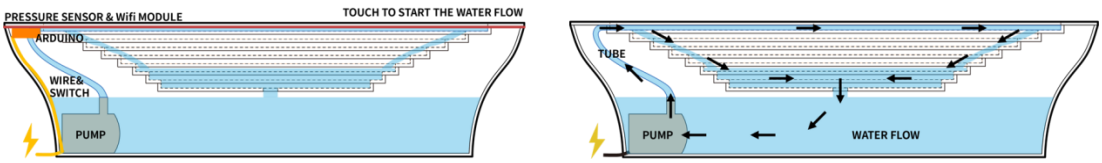
Fig, 5.20: Wood Model

It is manifest from Fig, 5.21 that the straight-line shape is transformed into a curve, which not only represents the flowing water but also expresses a sense of vitality of nature. The details of the CAD model are modified several times to make the shape more harmonious.



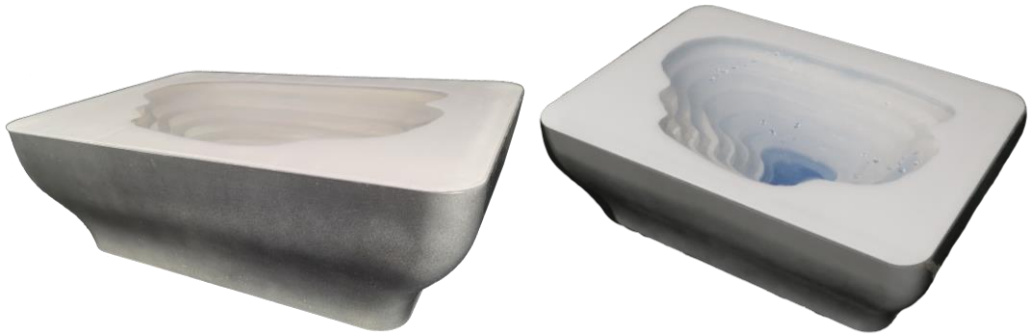
Fig, 5.21: CAD Models

According to Fig, 5.22, the water table uses Arduino, wifi module, pressure sensor, tube and water pump to achieve the interaction. It interacts with people by placing a pressure sensor under the desktop. As is shown in the right side of the figure, when a person touches the desktop, the pressure sensor feels pressure, the pump starts, and the water starts to flow. In addition, the table obtains weather information by the wifi module. When the weather condition changes, the pumping efficiency alters and the water level changes. For example, when it rains heavily, the pumping efficiency decreases and the water level rises.



Fig, 5.22: Mechanical Solution

The scale of the final prototype is 1:2. The inner part is made of MDF, which uses CNC to shape the wood, white emulsion to glue them together, glass cement to do waterproof treatment and spray paint to colour. The outer part is made of photosensitive resin by 3D printing. The desktop is made of PVC through laser engraving. Fig, 5.23 presents the functional model people can interact with.



Fig, 5.23: Final Prototype

It can be seen from Fig, 5.24 that there are two colour schemes for the water table to suit different people's preferences. The reproducible technical plan of the table is as follow: desktop is made of tempered glass with diamond cut on edge to make it exquisite. The outer and inner shells are all made of polypropylene (PP) through moulding and polishing.

Fig, 5.24: Rendering — Colour Schemes

5.2.4 Scenario test

Scenario test is conducting by showing users demo videos and photos (Fig, 5.25) of the water table because the final prototype is not full size. The demo video not only demonstrates the family and exhibition context but also presents how the table interacts with people and environment and how the projected AR interacts with visitors.

Fig, 5.25: Usage scenario

Seven people are invited to participate in the test, including four girls who had participated in the game test before and three boys. After seeing the picture of the physical model, everyone thinks the shape of table is strange. Three of them said it looks like a bathtub, two noted it is similar to a sink, and one indicated it likes a toilet. On the one hand, the feedback reflects that the design of appearance may not be successful, because nobody considers it is a table from the first glance. But on the other hand, it meets a requirement of speculative design, that is, the profile is unique and eye-catching. In addition, they asked why is there water in the table and what does this water represent? After explaining the water table and climate change, they all indicated that it deepens their understanding of environmental issues to some extent.

Then they watched the video to learn how the table interacts with people and weather and how the projected AR interact with visitors. Five participants (three females and two males) said that visualizing the changes in the real water table with weather stimulates their follow-up discussions on climate change and people's living environment in the future. Two other participants proposed that such way of visualizing the water table reduces the alienation between people and the environment because the invisible, obscure groundwater is actually the basis for human survival and this project makes people pay attention to it and connect it with the environment and ourselves. In addition, everyone agreed that people would ask questions when seeing the table and water flows, which indeed creates topics in social situations. However, a male proposed that the water table is only able to trigger discussions at the first time, and people will ignore the environmental value when seeing it again. Moreover, another boy believed that many people put idle items on the side table, which may affect the table's ability to interact with people. Furthermore, a girl considered that the table design is so complicated and weird that maybe nobody is willing to buy it.

6 Discussion and Conclusion

6.1 Outcome

In summary, this article adopts a research-through-design method to explore how to enhance people's understanding and connection to the environment through interaction design. The design objectives are raising individuals' awareness of climate change and reducing the alienation between people and environment. The author discovers two design directions through the literature and case study review, which are AR mobile game and AR interactive installation. The results of user test indicate that the latter solves research problems and achieves design objectives better. This research extends our knowledge of solving climate issues through interaction design.

In the first round of design, a female gamer who is Z generation and likes simulation and puzzle adventure game is chosen as the target user through user research. The game uses the Australian wildfire as a background story, which leads to a series of tasks to avoid disasters. In the game, players gain virtual rewards (creatures) by completing low-carbon actions in daily life. Natural disasters in reality will also affect the growth of animals and plants in the game. The author invites four users to test the game. Results show that the setting of game tasks and the rule of supervising users to complete tasks by taking photos are unreasonable. Although most of them indicate that playing games can improve their awareness of climate issues to a certain extent, there is still an obvious conflict that protecting environment protection requires an appreciation of nature, but mobile games alienate users from natural environment.

In the second round of design, the author determines to create a physical water table to represent the impact of climate change on groundwater through brainstorming and secondary research. The design context is Chinese hospitality. Specifically, when a guest's hand or teacup touches the water table, the water inside will flow, which attracts people's attention and triggers a conversation on groundwater and climate change. In addition, the water level can change with local weather with an exaggeration of the actual water table change. This target user is high-income yuppies who live in first-tier cities and like to see exhibitions. Through the user journey map, it is determined that the water table is divided into two production lines: one is a commercial table based on projection AR for interaction and used in the exhibition, and the other is a family side table based on Arduino for interaction. This research mainly conducts design process and user test for the side table. Participants in the scenario test are four female and three male (including the girls who participated in the game test). Results demonstrate that all participants think the shape of table is unique and eye-catching. Meanwhile, most users believe that the interaction design

of the table will raise people's awareness of climate change and reduce the alienation of people and environment. However, the design may be too aggressive for the user to buy it. In addition, the selling method that it is sold as a souvenir may cause a relatively short sale time.

6.2 Limitations

The findings in this report are subject to several limitations. The first and most important shortcoming is that there are too many differences between the two design works, which makes the comparison of these two projects meaningless to some extent. In addition, as the design progresses, the mistakes made before will not be made again. Therefore, it can be held that the second round of design has a greater chance to be better than the first round. Moreover, due to limited time and resources, the number of users participating in user test is too small, which may lead to inaccurate test results and increase deviation. Furthermore, this research conducts user test only by showing demo videos or simple prototypes (paper cards) because there are no full-sized model or fully functioned prototype, which will also increase the inaccuracy. Last but not least, it is a big regret for the author that the AR content design of the water table for exhibition use is not completed in a limited time.

6.3 Future Direction

This research has thrown up many questions in need of further investigation. The primary mission for future improvement is to complete the design of the other production line of water table. Precisely speaking, the design of interactive AR projection content should be finished. In addition, it would be interesting to assess the two kinds of water table and make a comparison for the reason that it reduces the variables between two design projects and increases comparability. The pros and cons of two interaction methods can be found out by comparing different product lines. However, this method is still limited by the variation of the table's usage context. Therefore, a better solution to compare different interaction method should be changing one variable of the water table at one time. For example, for the side table, the comparison can be conducted by only changing the way the table interacts with people or only the way it interacts with the weather. Lastly, full-sized prototypes must be made to allow the user to interact with and experience the product in reality.

References

Sunday, J. M. (2020) 'The pace of biodiversity change in a warming climate', *Nature: International weekly journal of science*, 580(7804), pp. 460. doi: 10.1038/d41586-020-00975-9.

Christopher L. S. *et al.* (2004) 'The Oceanic Sink for Anthropogenic CO2', *Science*, 305(5682), pp. 367. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=edsjsr&AN=edsjsr.3837507&site=eds-live&scope=site (Accessed: 14 April 2020).

U.S. Global Change Research Program (2017) *Climate Science Special Report: Fourth National Climate Assessment*, Washington, DC. doi: 10.7930/J0J964J6.

Hutchins, A. (2020) 'Trial by Fire', *Maclean's*, 133(2), pp. 60-67. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=asn&AN=141507259&site=eds-live&scope=site (Accessed: 14 April 2020).

Munch, R. (2020) 'Australia on Fire', *Commonweal*, 147(2), pp. 6-7. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=lfh&AN=141391800&site=eds-live&scope=site (Accessed: 14 April 2020).

Worland, J. and Gunia, A. (2020) 'What the World Sees As Australia Burns', *TIME Magazine*, 195(1), pp. 7. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=edb&AN=141092002&site=eds-live&scope=site (Accessed: 14 April 2020).

Pablo, U. *et al.* (2019) 'Indian Ocean Dipole: What is it and why is it linked to floods and bushfires?', *BBC*, 12(7). Available at: https://www.bbc.com/news/science-environment-50602971 (Accessed: 14 April 2020).

Judt, D. (2020) 'Australia Is Burning', *Nation*, 310(4), pp. 12. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=edb&AN=141353682&site=eds-live&scope=site (Accessed: 15 April 2020).

Crocker, R. and Lehmann, S. (eds.). (2013). *Motivating Change: Sustainable Design and Behaviour in the Built Environment* . 1st ed. London: Routledge.

Giuseppe, F. and Giancarlo, C. (2007) *Integrate business modeling and interaction design*. Available at: https://www.ibm.com/developerworks/library/ws-soa-busmodeling/ws-soa-busmodeling-pdf.pdf (Accessed: 22 November 2020)

Pirhonen, A. *et al.* (2005) *Future Interaction Design*. 1st ed. London: Springer. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=cat01010a&AN=xjtlu.0001507803&site=eds-live&scope=site (Accessed: 22 November 2020).

Norman, D. A. (2015) *The design of everyday things*. Revised and expanded edition. Basic Books, a member of the Perseus Books Group.

Walter, A., Kissane, E. and Wang, X. (2014) *Wang zhi qing gan hua she ji yu nei rong ce lue = Designing for emotion : the elements of content strategy*. Beijing: Ren min you dian chu ban she (网站情感化设计与内容策略 = Designing for emotion : the elements of content strategy / Aarron Walter, Erin Kissane 著 ; 王兴译).

Norman, D. A. (2015) *Emotional design : why we love (or hate) everyday things*. Revised and expanded edition. Basic Books, a member of the Perseus Books Group.

Schueffel, P. (2017). *The Concise Fintech Compendium*. Fribourg: School of Management Fribourg, Switzerland. Available at: http://www.heg-fr.ch/EN/School-of-Management/Communication-and-Events/events/Pages/EventViewer.aspx?Event=patrick-schuffel.aspx (Accessed: 19 November 2020).

Azuma, R.T. (1997), 'A survey of augmented reality', *MIT Press*, 6 (4), pp. 355-385.

Sherman, W. R. and Craig, A. B. (2019). *Understanding virtual reality : interface, application, and design*. 2ed ed. Morgan Kaufmann (The Morgan Kaufmann series in computer graphics). Available at: http://search.ebscohost.com/login.aspx?direct=true&db=cat01010a&AN=xjtlu.0001433425&site=eds-live&scope=site (Accessed: 19 November 2020).

Milgram, P. and Kishino, F. (1994). 'A Taxonomy of Mixed Reality Visual Displays'. *IEICE Transactions on Information System*, E77-D (12), pp. 1321-1329.

Bourguet, M. L. (2007). 'An Overview of Multimodal Interaction Techniques and Applications'. *Intelligent Information Technologies*. doi: 10.4018/978-1-59140-562-7.ch068.

Ishii, H. 'Proceedings of the Second International Conference on Tangible and Embedded Interaction (TEI'08), Bonn, Germany, 18-20 February 2008' (2008) *Association for Computing Machinery*, xv(xxv). doi: https://doi.org/10.1145/1347390.1347392

Sharlin, E. *et al.* (2004) 'On tangible user interfaces, humans and spatiality', *Personal and Ubiquitous Computing*, 8(5), p. 338. doi: 10.1007/s00779-004-0296-5.

Nizam, S. S. M. *et al.* (2018) 'A review of multimodal interaction technique in augmented reality environment', *International Journal on Advanced Science, Engineering and Information Technology*, 8(4–2), pp. 1460–1469. doi: 10.18517/ijaseit.8.4-2.6824.

Dunne, A. and Raby, F. (2013) *Speculative everything: design, fiction, and social dreaming*. Massachusetts: The MIT Press.

Malpass, M. (2015) 'Speculative Everything: Design, Fiction, and Social Dreaming (Book Review)', *Design and Culture*, 7(2), pp. 268. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=edo&AN=ejs36910880&site=eds-live&scope=site (Accessed: 19 November 2020)

Malpass, M. (2019) *Critical design in context : history, theory, and practices*. Bloomsbury Academic, an imprint of Bloomsbury Publishing Plc. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=cat01010a&AN=xjtlu.000143315 8&site=eds-live&scope=site (Accessed: 19 December 2020).

Jharrower. (2014) *REVITAL COHEN*. Available at: https://artscy.sites.ucsc.edu/category/synthesists/ (Accessed: 19 November 2020).

Rittel.J. and Webber. M. (1973). 'Dilemmas in a General Theory of Planning'. *Policy Sciences*. 4 (2): 155–169.

Alcañiz, M. *et al.* (2017) *Serious Games. [electronic resource] : Third Joint International Conference, JCSG 2017*, Valencia, Spain, 23-24 November 2017, Springer International Publishing.

Ouariachi, T., Gutiérrez-Pérez, J. and Olvera-Lobo, M.-D. (2018) 'Can serious games help to mitigate climate change? Exploring their influence on Spanish and American teenagers' attitudes', *PsyEcology*, 9(3), pp. 1–395. doi: 10.1080/21711976.2018.1493774.

Caitilin de Bérigny *et al.* (2014) 'Tangible User Interface Design for Climate Change Education in Interactive Installation Art', *Leonardo*, 47(5), pp. 451–457. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=edsjsr&AN=edsjsr.43832953&site=eds-live&scope=site (Accessed: 24 December 2020).

Jansen, Y. (2014) 'Physical and tangible information visualization'. Other [cs.OH]. Universit´e Paris Sud - Paris XI. Available at: https://tel.archives-ouvertes.fr/tel-00981521 (Accessed: 24 December 2020).

Colavito, M. *et al.* (2020) 'Integrating art and science to communicate the social and ecological complexities of wildfire and climate change in Arizona, USA', *Fire Ecology*, 16(1). doi: 10.1186/s42408-020-00078-w.

Design Council. (2015) *A study of the design process*. Available at: https://www.designcouncil.org.uk/sites/default/files/asset/document/ElevenLessons_Design_Council%20(2).pdf (Accessed: 24 December 2020).

Brown, T. and Kātz, B. (2011) *Change by design : how design thinking transforms organizations and inspires innovation*. Shenyang: Wan Juan Publishing Company.

Secondary Research (no date) Available at: https://www.designkit.org/methods/secondary-research (Accessed: 24 December 2020).

Krzych, Ł. J. *et al.* (2018) 'The Likert scale is a powerful tool for quality of life assessment among patients after minimally invasive coronary surgery', *Polish Journal of Thoracic & Cardiovascular Surgery*, 15(2), pp. 130-134. doi: 10.5114/kitp.2018.76480.

Zablith, F. and Osman, I. H. (2019) 'Review Modus: Text classification and sentiment prediction of unstructured reviews using a hybrid combination of machine learning and evaluation models', *Applied Mathematical Modelling*, 71, pp. 569–583. doi: 10.1016/j.apm.2019.02.032.

Rapid Prototyping (no date) Available at: https://www.designkit.org/methods/rapid-prototyping (Accessed: 24 December 2020).

Cannon-Bowers, J. A. and Bowers, C. A. (2010) *Serious game design and development: technologies for training and learning*. Hershey: IGI Global. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=cat07934a&AN=xjl.00037283&site=eds-live&scope=site (Accessed: 24 December 2020).

Graham, K. (2019) 'Global warming is creating a groundwater 'time bomb'', *SCIENCE,* 1(4), Available at: http://www.digitaljournal.com/tech-and-science/science/global-warming-is-creating-a-groundwater-time-bomb/article/541584 (Accessed: 29 December 2020).

Water Sources in Shanghai (2010) Available at: http://chs.ubc.ca/china/shanghai.pdf#:~:text=There%20are%20many%20other%20surface%20water%20sources%20in,Huangpu%20River.%20Additionally%2C%20there%20are%20also%20newly%20constructed (Accessed: 29 December 2020)

Notes

https://earthobservatory.nasa.gov/images/146096/thick-smoke-blankets-southeastern-australia

https://xray-mag.com/content/meet-maslow /meet-maslow

https://www.semanticscholar.org/paper/Augmented-reality%3A-a-class-of-displays-on-the-Milgram-Takemura/96ac874ea8938ad6aa4911774dc93ba4a5c845b0

https://www.slideshare.net/marknb00/lecture9-ar-technology

https://www.cohenvanbalen.com/work/life-support

https://link.springer.com/chapter/10.1007/978-3-319-70111-0_22

https://www.springer.com/gp/book/9783319701103

https://www.researchgate.net/publication/268516527_Reefs_on_the_Edge_An_Installation_Artwork_about_Coral_Reefs_and_Climate_Change

http://dataphys.org/list/durrell-bishops-marble-answering-machine/

https://artmuseum.arizona.edu/events/event/fires-change

https://3dprintingindustry.com/wp-content/uploads/2017/01/Double-Diamond-Methodology-01_1000.jpg

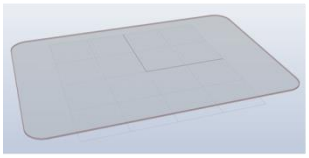
https://en.wikipedia.org/wiki/Water_table

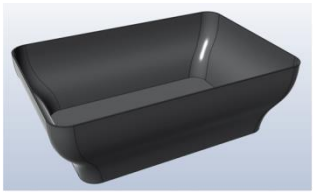
https://www.sohu.com/a/19325086_180734

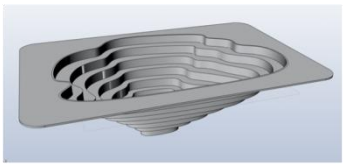
http://m.quanjing.com/imginfo/bji04540080.html

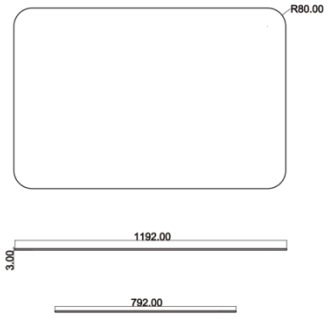
Appendix

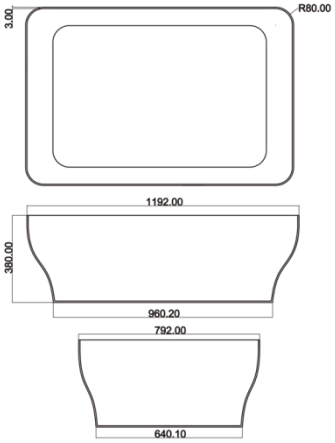
This appendix mainly supplements and demonstrates several pictures of the water table, including production process photos, prototype photos, size diagrams, rendering images, scenario images, and video screenshots.

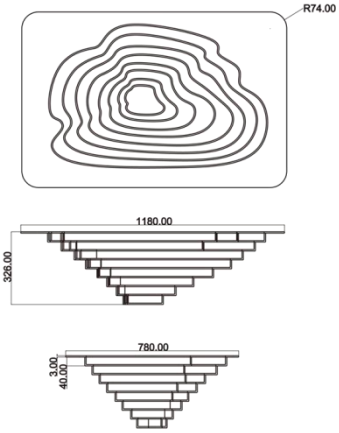







R80.00
1192.00
3.00
792.00


3.00
R80.00
1192.00
380.00
960.20
792.00
640.10


R74.00
1180.00
328.00
780.00
3.00
40.00