

An IoT approach to bridging virtual and physical reflective learning experiences in museums

By

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Thesis submitted to The University of Nottingham for the degree of Doctor of Philosophy, November 2019

Acknowledgement

Firstly, I would like to express my sincere gratitude to my supervisor Dr. Marina Ng for her continuous support in my Ph.D. study and for her patience, motivation, and immense knowledge. She helped me throughout the research and in the writing of the thesis. I could not have imagined having a better advisor and mentor for my Ph.D. study. I would also like to thank my external supervisor Prof. Tim Brailsford, for his help during the project and in hosting my research in the UK. I value our in-depth discussions on various research problems.

Besides my supervisors, I would like to thank the rest of my friends and research team members: Prof. Claire O'Maley, Lo Wei Hong, Alan, Lin Jia Qi, Zhang Wen Yuan and Quah Chia Yi for their insightful comments and encouragement, but also for the hard questions they asked to help me widen my research from various perspectives.

In addition, I would like to thank Prof. Steve Benford, Dr. Ben Bedwell and Dr. Boriana Koleva for their supervisory support and research collaboration during my PhD mobility exchange stint in the Mixed Reality Lab, University of Nottingham, UK. I am grateful for their idea suggestion on the IoT Toolkit in the thesis. Special thanks also go to Miss Melissa Chan and her team at the Baba Nyonya Heritage Museum, Malacca. It was a fantastic experience working with them.

A special thanks to my family. Words cannot express how grateful I am to my mother, father, my mother-in law and father-in-law for all of the sacrifices that they have made on my behalf. Last but not least, I would like to express my deepest appreciation to my beloved wife, Iree who always support me.

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Abstract

In the past, museums have been places where history and culture are narrated. In recent years, many museum research projects have used tangible systems and mobile applications to replace or augment the traditional museum tour. However, many of these projects provide what are essentially electronic labels rather a new narrative modality. The reason behind people visiting museums is to have declarative learning which means to acquire information that they can speak about. Issues such as social experiences, reflection and connections between cultures, are important parts of the experience. New approaches to help visitors learn and reflect upon these cultural issues in support of museums' new roles of shaping cultural identify and community building to be explored. This research collaborated with the Baba Nyonya Culture Heritage Museum, Malacca to focus on the Baba Nyonya culture. Because of the cultural diversity of the country, the rich, fusion culture of the Baba Nyonya cuts to the heart of this. A pilot museum study was conducted to enhance visitor engagement in cultural learning and reflection by exploring IoT approach to support physical interaction and multisensory experiences. However, the pilot study revealed limited evidence of cultural reflection. In order to improve the result of pilot study, particularly to trigger more reflection, the museum visiting experience was designed as an IoT serious game to include five interactive exhibits - an online trading game, improved Batu Boh and Goldsmith simulators, a new lantern mapping and a virtual house decoration station. The IoT serious game focuses on extending the interactive exhibits to incorporate elements of serious games (games with an educational motivation) to further enhance the visitor experience and encourage cultural reflection using IoT technology. The main museum study design showed how an IoT serious game can be developed with the help of design goals serving as guidelines. The result of the main museum study revealed most participants achieved learning gain to form new understanding of the Peranakan culture and considerably high success in engaging visitors and supporting different levels of reflection. One of the main contributions of the museum studies is the synthesise and translation of design lessons learned as a guideline for future IoT game development. The last phase of research involved solving some of the challenges identified in the study, specifically in difficulty with IoT game ideation and establishing communication between IoT sensors and virtual game to allow future museum teams to build similar game experience more easily and effectively. The project introduced an IoT toolkit for future designers to consist of an IoT card game to support game design ideation and IoT development kit as plugin between IoT sensors and the game development platform. The contributions of this thesis are a set of prototype demonstrators, toolkits and guidelines for designing IoT serious game that will aid future developers in designing for cultural learning and reflective experience in museums.

Chapter 1. Introduction

1.1 Project Background

Previously, the description of museum artefacts was largely dependent on tour guides and information cards (Marshal at al., 2016). Today, these concepts tend to be digitalised. Along with the development of mobile and tangible technologies, museums have started to present descriptions of museum artefacts through multimedia content using mobile applications or tangible interaction systems. Although the use of multimedia presentations in museums has improved the museum visiting experience, the interaction between museum artefacts and visitors are still lacking and mostly passive in nature. Most often, the cultural heritage artefacts cannot be touched by visitors. Recent research has focused on using physical replicas to overcome this lack of interactions to make museums and their artefacts more engaging for visitors. Emerging technologies such as 3D printing and Internet of Things (IoT) have been used to create tangible smart replicas to access an additional layer of content that complements the traditional factual information that is generally provided about artefacts in a museum (Marshal at al., 2016). Other research has explored the use of digital technologies with games to improve museum visiting experiences. For example, to enhance learners' motivation to learn about fossil in a museum, Yoshida et al. (2015) developed a virtual paleontological environment to support experiential learning with entertainment. Such games, designed for a primary purpose other than pure entertainment is known as serious games (Lamaarti et al., 2014). From the review study conducted by Lamaarti et al. (2014), many serious games have been developed for promoting cultural learning (Sagae et al., 2010; Froschauer et al., 2011; Bellotti et al., 2012). However, current research studies on serious games are still limited to mobile and desktop games where users often learn about culture and history from the vicinity of their homes (Susi et al., 2007; Coenen et al., 2013; Antoniou et al., 2013).

The role of museums itself has changed over the years as education is not the only goal for visitors to visit a museum (Kaplan, 1993). Museums now find that they play an increasing role in supporting the development of communities other than their traditional role of collecting, preserving and sharing rich collections. Museums can help emphasise the uniqueness of community's identity and be able to bring different community groups together. By having an open access to objects, information and knowledge visitors can see for themselves how cultures may be reflected in ways that encourage new connections (Kelly, 2007). Technologies that focus strictly on the learning goal of visitors

may actually impoverish their experiences by drawing attention away from these important aspects of museum-going.

1.2 Research Statement

The technological revolution has had a major impact upon museums, and many of them make very effective use of a wide variety of interactive technologies. However, there is a paradoxical concern that technologies that focus too much on learning goals can distract from the meaning making processes, which are the very things that the technology is trying to promote (Cosley et al., 2008). The key issue is to consider how the technology promotes discussion and reflection in order to facilitate meaning making. Designers have demonstrated an increased interest in designing for reflection (Sengers et al., 2005; Baumer, 2015). Reflection can be described as a "generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations" (Boud et al., 1985). Fleck and Fitzpatrick (2010) further synthesized the literature on reflection into a framework consisting of different levels of reflection. There have been some examples of how technology can be used to support reflection in learning (Lin et al., 1999), teaching (Fleck & Fitzpatrick,2009), health (Mamykina et al., 2008), persuasive behaviour (Ghajargar et al., 2018), personal informatics (Li et al., 2010) and design (Gaver et al., 2003). Although, there has been some studies that focussed on exploring possible approaches to reflective design in cultural settings, little evidence is provided so far to suggest their effectiveness in engaging visitors in reflective thoughts (Baumer et al., 2014). In times of increasing ethnic tensions throughout the world, the role of museums as repositories of heritage is ever more important to help people understand and reflect on cultural identities e.g. cultural similarities and differences towards wider national unity. This type of thinking in museum design is quite new, and there is as yet no received wisdom on how designers should create museum experiences that evoke deep, cultural reflections to help shape community identity.

There is still limited research that focuses on designing for reflection in museum settings. A few research efforts were made, for example to encourage visitors' reflection by encouraging visitors to think about the past and discuss using social media (Bammpatzia et al., 2016) and in another study, to help visitors make connections with exhibits and other visitors by highlighting the thoughts shared by visitors (Cosley et al., 2008). On the other hand, Muntean et al. (2017) outlines recommendations for designing values into interactions more generally and for tangible interactions specifically in ways that support visitors' experience and understanding of specific cultural values through technology. More recently and related to the project, there have been interested to investigate how

IoT technology can be used to support reflection (Ghajargar et al., 2018) and the effectiveness of games in supporting reflective experiences (Mekler et al., 2018). While there may be a lot of research projects that support reflective experiences, it is still not clear how designers may design interactive systems that will evoke deeper, cultural reflections to help shape community identity in a museum setting.

1.3 Research Questions

The aim of this research is to explore new technological approaches to support learning and reflections in museums. The proposed project will address the following research questions:

- How can emerging Internet of Things (IoT) technology be used in museums to encourage learning engagement as well as reflection of visitors? What tools can be used to influence visitors?
- How can a serious game be designed to create deeper learning engagement and reflection using IoT-enabled physical environments?
- How effective will IoT games be in facilitating the understanding of cultures and information about artefacts?

1.4 Research Goals and Objectives

The above research questions will be addressed through the following research objectives:

1. To design and develop interactive system in museum settings to enhance visitor's learning experience.
2. To incorporate game elements in the interactive system to facilitate deeper learning engagement and reflection.
3. To develop an IoT Toolkit for developing future tangible serious games.
4. To propose guidelines for designing for reflection in museum settings to support cultural identity formation and community building.

1.5 Methodology

This section describes the research methodology of the thesis. In more detail, it describes the research process, design approach, evaluation methods and data analysis that were carried out to achieve the above objectives.

In terms of research context, the project was carried out as part of a research collaboration with Baba Nyonya Heritage Museum. It is located in the old district of the World UNESCO area of Malacca town. The project was in line with the museum's vision of bridging communities to Malaysia's history through the Baba Nyonya culture. Initial ethnographic studies, information gathering and brainstorming sessions were conducted involving museum curators in a participatory design process over a 6-month period. It was found that the existing personal guided museum tours lacked interaction between visitors and museum contents and failed to cultivate or sustain the cultural learning interest of children. As a huge number of visitors to the museum are school and family groups with children, the project focused on designing interactive exhibits that could become part of a self-guided tour for families and children. In the initial stage of research, a pilot study was conducted to investigate the effectiveness of IoT approach involving multisensory and physical interactions in enhancing visitor engagement, and its impact on learning gains. Two interactive exhibits were developed using the Test-driven development method and evaluated in a public trial using qualitative method to include questionnaires, user observation and video analysis.

Building on the results of the pilot study, the initial interactive exhibits were further improved through design iterations. During the second phase of research, the project incorporated game elements and IoT technology to create an IoT serious game experience with the aim of triggering deeper levels of reflection among museum visitors. The game experience was evaluated in a main museum study through a public trial and participated by family groups as a self-guided interactive game tour, to encompass a pre- and post-game learning activity. The evaluation of the main museum study was based on qualitative method where data was collected through surveys to measure learning gains, user observations and interviews at the end of the game experience and 3 days after the tour to evaluate the level of reflective learning through the IoT serious game experience. The audio transcriptions were transcribed and analysed by applying the reflection framework by Fleck and Fitzpatrick (2010). Lessons learned from the experience of designing and developing the museum studies were translated into a set of guidelines for designing future IoT serious games in museum settings.

The last phase of research involved solving some of the challenges encountered in the design and development of the IoT serious game experience to allow future museum teams to build similar game experience more easily and effectively. For this purpose, the project developed an IoT toolkit for future designers to consist of an IoT card game to support game design ideation and IoT development kit as plugin between IoT sensors and the game development platform. The IoT toolkit was evaluated by using surveys and interviews to determine user acceptance of the toolkit and its effectiveness in aiding game ideation and development.

1.6 Research Scope and Limitations

The research concerned in the design, development and evaluation of a self-guided museum tour for family groups based on IoT and game approach. The impact of the research work is the long-term and permanent deployment and adoption of the prototype interactive exhibits developed here as part of the future museum visiting experience. The research also concerned providing technological solutions to overcome identified challenges of designing and developing future IoT serious games in museums. The research study encompassed multidisciplinary fields and involved the research collaboration and input of interdisciplinary experts from various fields to include Human Computer Interaction (HCI), education, learning psychology and museum study. The research scope and limitations of this research include the following:

1. The research focused on the Peranakan culture, because of the cultural diversity of the country, the rich, fusion culture of the Baba Nyonya cuts to the heart of this. The self-guided interactive tour was designed to facilitate inter-cultural and inter-generational dialogues about cultural identity targeting all-age family groups. This research supported the new role of museum in helping visitors understand similarities and appreciate cultural differences towards community building endeavour.
2. The research explored IoT approach to highlight cultural themes with associated historical artefact. The project experimented with ways to create augmented artefact or smart objects through three techniques: 1) re-creating artefact as replicas, 2) augmenting artefact with sensors and 3) digitally enhancing artefact through ambient projection.
3. The research concerned developing an extended museum visiting experience, consisting of multiple interactive exhibits as part of a complete and real museum tour. The work involved designing and developing interactive exhibit stations to

fit the physical museum environment and context, while being connected through a game storyboard and IoT technology.

4. This research involved evaluating the effectiveness of IoT serious games, by combining IoT and game approaches to deepen visitor engagement and facilitate visitor learning and reflection. Extending the user engagement goal to include reflection, has been applied in other fields especially within formal education settings, but an important emerging field in HCI design which is still lacking in museum settings. The project explores merging physical and digital interactions to deepen learning and reflective experience for visitors.
5. The evaluation method of main museum study applied the reflection framework by Fleck and Fitzpatrick (2010) where reflection can be classified and defined according to four levels of reflection. From lessons learned, the research proposed design guidelines for designing reflection in museums.
6. The research introduced an IoT toolkit to overcome current limitations in creating IoT serious game in museums. The IoT toolkit consisted of an IoT card game for ideation and development kit which was evaluated by university students and researchers. However, due to time and project limitations, the toolkit has not been evaluated by museum professionals and will remain as a future work.

1.7 Thesis Structure

This thesis consists of nine chapters, covering from literature background to include state of the art museum technologies and case studies, emerging technological design and development tools and theory of reflection, to museum studies and evaluation. Here is an overview of the content of each chapter:

Chapter 2 includes three section which is digitalisation of museum, existing toolkit and reflection. Digitalisation of museum describes the role of museum and how it is changing and becoming increasing important in modern (yet confusing) times, especially to support cultural identity formation and community building. The challenge of museums to attract visitors and increase their engagements with the artefact and museum content is highlighted here, followed by an overview of the recent design strategies that museums employ to increase interactivity, immersion and fun through gamification. The subsection titled “Technology in Museum” describes how technology can enhance museum experience with various examples of Human-Computer Interaction (HCI) technology ranging from Virtual Reality (VR) to IoT being presented. Existing toolkit reviews existing design and development toolkits available to include software toolkit, hardware toolkit

and card-based ideation tools which can be used for creating innovative public experiences based on emerging IoT technology (as the technological platform used by the project and basis for IoT toolkit development in the later part of thesis). The review presents the advantages and limitations of existing toolkit designs. Reflection describes the definition of reflection. Concepts of reflection from the perspective of education and HCI are presented, to include a reflection framework (applied to main evaluation). Examples of how different types of technologies have been designed to support reflection in various fields such as education and healthcare are presented. The chapter highlights the lack of research designing for reflection in museum settings.

Chapter 3 describes the design and development of an initial museum experience which consists of two interactive exhibits. The chapter details the museum context and initial data gathering to identify requirements for the exhibits. The research focused on creating multisensory experience and increasing interactivity through physical interactions with artefact to enhance visitor engagement. The chapter describes the design of the exhibits and presents the results of the pilot study the end of the chapter.

Chapter 4 describes the second design iteration of museum experience and exhibits to include more focus on IoT approach and gamification. The pilot study extends to include three more exhibit stations, all connected using the IoT to create an IoT serious game experience. The chapter describes the design requirements, system design and infrastructure and how the game experience was evaluated in a main museum study. The results of the evaluation are presented in this chapter, highlighting some evidence of the museum game experience in engaging visitors and aiding their learning and reflection of culture.

Chapter 5 describes the details the benefits of an IoT toolkit developed to help future designers brainstorm and develop similar IoT serious game in lesser time compared to conventional way. The chapter introduces two components: an IoT card game and IoT development kit that made up the IoT toolkit. The chapter presents the design process of the card game and development kit and their evaluations by Computer Science (CS) major students and developers. The results of evaluation are being presented here.

Chapter 5 presents topic of discussions associated to the three phases of research. The discussion considers how the research questions have been met and contributes to understanding on the effectiveness of IoT serious game approach in supporting visitor engagement in museums, leading to learning gains and reflection and how IoT and game

elements can be implemented for this purpose through a set of design goals and guidelines. The chapter also discusses the potential of the IoT card game and development kit as a useful tool for future designers to implement IoT serious game.

Chapter 6 concludes the work presented in this thesis and outlines possible future work. The chapter highlights the contributions of the thesis work in presenting a prototype demonstrator in the form of a real museum interactive game tour for families that is deployed and made available publicly on-site the Baba Nyonya Heritage Museum, and understanding of how technology, specifically IoT serious game can be used and if it is effective at triggering reflection and if yes, at what levels of reflection. The potential of the IoT toolkit, as another main contribution of the thesis work is also highlighted here.

Chapter 2 Literature Review

2.1 Digitisation of Museum

2.1.1 The Changing Role of Museums

The term of museum is derived from Greek word ‘Muse’. It means a storehouse of knowledge (Devi, 2017). The museum origins can be traced back to the 19th century (Genoways and Andrei, 2016). The role of museum is more like an exhibition centre. It is a place that allows public access to collection of artefacts. At the end of 19th century, museology becomes a research topic concerning education, conservation and administration of museums. The role of a museum was not only limited to presenting collection but recording history documents and educating people. However, during the 20th to 21st century, the functions of a museum include preservation of cultural heritage, shaping cultural identity and building communities.

2.1.1.1 Preserving Heritage

Persevering cultural heritage is a big challenge to cultural heritage institutions. Without the preservation, heritage will decay and disintegrate from human history. According to the definition of United Nations Educational Scientific and Cultural Organization (UNESCO), there are three types of heritages which are natural heritage, tangible heritage and intangible heritage. The natural heritage is defined as outstanding physical, biological and geological features, such as national parks. The tangible heritage defined as a monument, group of buildings or sites of historical, aesthetic, archaeological, scientific, ethnological or anthropological value, such as a vast temple, a group of historical buildings etc. The intangible heritage defined as all forms of traditional and popular or folk culture, such as oral traditions, customs, languages, music, dance, rituals, festivities and traditional (Kirshenblatt-Gimblett, 2004; Ahmad, 2006). Nowadays, the museum plays an important role in preserving and protecting cultural heritage and knowledge.

For example, the Vietnam Museum of Ethnology highlights the values of traditional craft in an exhibition supported by UNESCO which involves teaching the making of traditional crafts to children and youth (between 10-14 years old). In short, the museum preserves the cultural heritage through education (Perera, 2015). In Malaysia, a heritage building was converted to a cultural heritage museum to preserve the traditional skills of building making (Harun, 2011) (see figure 2.1). Another research by Elsorady (2014) investigated

the reuse of heritage building as museums to provide better cultural experience for visitors in order to promote cultural heritage. In conclusion, the museum becomes an important institution to preserve cultural heritage.



Figure 2.1: Bangunan Suluh Budiman, University Pendidikan Sultan Idris is a National Heritage Building (Harun, 2011)

2.1.1.2 Shaping Cultural Identity

Cultural identity refers to cognitive and affective appreciation of group membership. Cultural identity plays positive roles in the lives of young generation (Vedder and Van, 2017). In other words, understanding one's cultural identity helps young generation develop a sense of belonging. Furthermore, understanding cultural identity increases national unity and tolerance in a country.

However, the role of museum to help shape cultural identity is relatively new, but its importance has been highlighted in some museum studies. For example, Crinson (2001) has researched the role of national museum since the independence of West Africa where the museum is not only good for tourism but also a great way to educate the local community of cultural identity. In addition, it helps to add a sense of common and national agreement and identity for the country. Similarly, Bruijne (2016) has investigated the role of National Museum of Ghana since its independence in 1957 which study shows how the museum is used as a tool help the newly independent country to develop cultural identity and national unity.

Overall, the role of museum in educating and shaping cultural identity is a new research area for museology. In addition, the case studies of West Africa shows form cultural identity can be extended to community building and national identity. The museum plays an important role in building cultural identity in the community.

2.1.1.3 Community Building

Building strong relationships with local communities allow museums to meet mission related goals, and support community needs. Having strong community relationships allow museums to maintain current audiences as they change, attract new audiences, and demonstrate the relevance of the museum to the community.

In recent years, community building becomes one of new design strategic of museums. For example, the Vietnam museum of ethnology designed its exhibition hall to help visitors understand the cultural relationships between Vietnam and other countries (Van, 2006). The museum curator believes that the exhibition hall will play an important role because cultural understanding is necessary to fully achieve international political and economic integration and exchange in the face of globalization. The cultural information includes the political, cultural and environmental conditions of today, and the past. This information provides basic stability and development in the region.

Another study from Kelly (2001) introduced the role of museums between Indigenous communities and Australia. In Australia, museums worked closely with Indigenous communities for many years to meet the needs of Indigenous communities and to promote reconciliation through understanding (Kelly, 1999). These community museums play roles on collecting and displaying repatriated artefacts, host exhibitions and conduct educational programmes. Nowadays, museums are becoming a centre to maintain relationship between community.

In addition, Sozanski (2010) reports that many art museums have been upgraded and having facilities that are not related to art design. For example, the James A. Michener Art Museum announced its plan to add a new art-free wing for activities as concerts, lectures, and receptions (Sozanski, 2010). The Philadelphia Museum of Art holds an event called Jazz Fridays and the Museum of Modern Art offers yoga classes for public (Sozanski, 2010). This event aims to attract new audiences that may not deeply interested in arts but may want to spend time with friends and family in the interesting community-based surrounding. This kind of environment also groups different types of people who have similar interests and builds their social community.

In conclusion, museums play a role in community building and maintaining relationships between community. This could be done by providing a social space for people who have similar interests. The above study in Australia shows how museums promote

reconciliation through understanding to help maintain the stability and unity of a region and country.

2.1.2 Enhancing Museum Visitor Experience

Along with the changing role of technology in museums, the technology provides different functions to museum. In the field of Human Computer Interaction (HCI), a growing number of research and museum studies focus on enhancing museum experience (Thom-Santelli et al., 2006; Sabiescu et al., 2018). Nowadays, the museums are re-evaluating their position in relationship with their audiences, while new technologies are changing the very concept of the museum. HCI researchers are now challenged to use technology to maximise impact of the museum visiting experience (Tomiuc, 2014).

The use of technologies provides new ways for visitors to experience museum contents. There are two new forms of museum experience that can be created (Stogner, 2009). The first is the media-enhanced on-site experience: richly multi-sensory, contextualized, experiential and immersive. It is narrative-driven. It draws a diversity of people together and provides a collective experience. The second is the media-driven off-site experience that is personalised, on-demand, global and enables a vast sharing of information and personal experience. These types of experience reflect the new vision of museums that are now visitor centred and focused on reaching out to multiple audiences, while expanding their role of on-site and on-line cultural trend-setters (Tomiuc, 2014). The following section will be discussing some existing design strategies employed by museums to increase visitor engagement in museums.

2.2.2.1 Designing for Interactivity

A way to increase visitor engagement with exhibits is to design for visitor interactivity. According to the classification of Carrozzino and Bergamasco (2010), interactivity can be classified as device-based interactivity and natural interactivity. The device based interactivity is driven by the hardware, such as touch screen. The natural interactivity is driven by body, such as gesture recognition and speech recognition.

Kinaesthetic interaction is defined as interaction through body movements and hand gestures (Koutsabasis and Vosinakis, 2018; Fogtmann et al., 2008). The implementation of kinaesthetic interactions helps to enhance usability and create fun learning in the interactive system. For example, research by Panayiotis and Spyros designed an

interactive system with kinaesthetic technology to convey cultural heritage by making use of ancient tools and constructing artworks. In another study, two user studies were performed to compare gestures against button-controlled interactions for navigation and 3D manipulation. The result shows most users preferred kinaesthetic interactions (Dias et al., 2016).



Figure 2.2:A circular menu of icons (left) appears around a tangible shell when it is placed on the tabletop (right) (Chu et al.,2015)

In cultural museums, most of artefacts cannot be touched by visitors. As such a number of researchers have explored the use of tangible interfaces to afford natural physical interactions with digital stories (Chu et al., 2015). In the research by Vaz et al. (2016), the researchers designed an interactive system to trigger narrative contents through tangible design which pleased the visitors. In another example, Chu et al. (2015) designed an interactive system that integrates multi-touch tabletops and tangible interfaces to help students learn about historical and cultural concepts. Visitors are allowed to put a tangible replica object and record their own story through interaction (figure 2.2).

2.2.2.2 Designing for Immersion

Immersion was defined as the illusion of feeling in a specific time and place. Recently, there is a growing trend in creating immersion experience to engage visitors in museums. The immersion experience can be supported by sound, visual and smell.

Using sound is a way to design immersive environments in museum. Hjortkjær (2019) presented an immersive experience in a Danish museum which used sound installations to help museum visitors experience history through their senses rather than simply view the description of museum artefact. An effective immersive narrative not only shapes the exhibition design, it provides a bridge between the visitor's own life experiences and the objects that represent another time and place (Stogner, 2011). Marshall et al. (2016) proposed a story narrative case study that combine story and the sound of war to present

the story during World War I. The research found sound has a special relationship with emotional response. The combination of storytelling and sound bring historical facts and events closer to visitors.

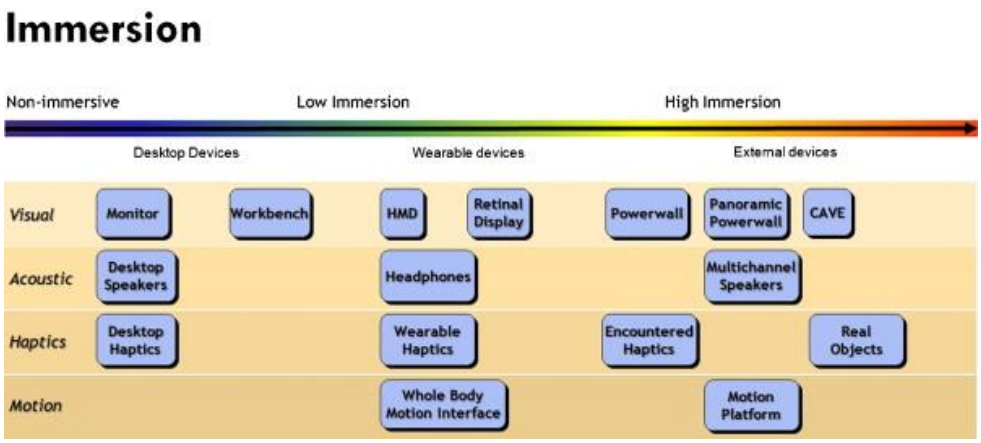


Figure 2.3:Classification of VR Immersion (Carrozzino and Bergamasco, 2010)

Designing for immersion can also include support for multisensory experience such as by combining visual sound and motion. Some researchers focus on designing for multisensory experience through Virtual Reality (VR). Carrozzino and Bergamasco proposed a classification of VR devices on the immersion axis as shown in figure 2.3. In the classification, it shows VR provides immersive experience from visual, acoustic, haptics and motion. Stogner (2011) examined several studies on multisensory experience in museum which research found that sensory immersion system engages the senses to create a heightened emotional and cognitive connection that ignites the imagination. However, there is still limited research that focuses on designing immersive experience with smell. Existing museum studies tend to focus on creating playful, immersive experience through visual, sound and motion.

2.2.2.3 Gamification

Recently, there is a trend to enhance the museum experience through gamification. Gamification is defined as the trend that connects the game with different elements or area, such as serious games, pervasive games, alternate reality games, or playful design (Deterding, 2011). Previous study highlights the potential of applying gamification to increase visitor engagement in museums (Noor, 2016). In addition, Cesário et al. (2017) highlights the potential of gamification to promote education through game experience.

As modern museums face issue of decreasing numbers of visitors, gamification plays a role to attract visitors through enhanced museum experience. There have been a

number of game studies which demonstrate a playful approach to develop interaction between visitors and artefacts (Fleck el al., 2002; O'Hara et al., 2007; Sánchez, 2011; Döpker et al., 2013; Martin et al., 2018). Paliokas (2015) proposed a serious game approach to combine education and gamification in museum. The term 'serious game' was defined by Clark Abt in the 1970s and it became popular in 2002 (Wilkinson, 2016). Serious game aims to integrate entertainment game with motivation for players. Serious game has been adopted to enhance the learning experience in museums. Cesário et al. (2017) presented a study that was conducted to assess the engagement of children through treasure hunt games. The evaluation result shows children being engaged and enjoy the museum space through a gamified approach. Haddad (2015) pointed out that serious games can be an effective way to increase the children's learning interest in cultural heritage.

In addition, Cesário et al. (2019) proposed a guideline for combining museum narrative content and gamification by listing down six types of enjoyable experiences to attract visitors in the museum:

- Clues: Clues game guide visitors to explore the museum through playful experience. The authors claim that Clues game encourage visitors to explore the different space of the museum. The culture also highlights attention from the visitor. The activity may increase their knowledge by solving the clues.
- Treasure Hunt: The treasure hunt game developed an immersion experience for visitors. The treasure hunt is similar to Clues game but treasure hunt games with more elements, such as a reward. The reward helps to encourage visitors to explore the museums.
- Quiz: The Quiz element supports museums with education content. The authors point out that that quiz is one of the most effective ways to transfer knowledge to visitors.
- Collection: The concept of collect pieces from big picture or puzzle helps visitors to create emotional involvement loop. The collection concept helps visitors to understand different motivation behind collecting game.
- Simulation: The simulation technique helps visitors to simulate the building process of the artefact. The simulation technique allows visitors to get a deeper understanding of artefact.

- Timeout strategy: This approach request visitor solves the task in certain time. But the time out strategy needs carefully crafted into the logic and purpose of the museum visit. If the game is run too fast, visitors may lose the fun of it.

Previous studies highlight the potential of gamification as one of the most effective ways to attract museum visitors and achieve education engagement. This research aims to explore a serious game approach to enhance deeper engagements in museum.

2.1.3 The Role of Technology in Museum

Since the 1950s, portable electronic guidebooks have been implemented in museums (Grinter et al., 2002). Recent technological developments encouraged some managers of art museums to deploy novel interpretation devices in their exhibitions, in particular PDAs and touch-screen computers (Vom Lehn and Heath, 2005). The portable electronic guidebook shows the different possibility for the museums. Grinter et al. (2002) developed a portable guidebook system to enhance social experience. With the portable electronic guidebooks, the independent users can share their thoughts and experiences with other users. Another research from Karreman et al. (2015) developed a tour guide robot for interactive tours and adaptive content to visitors. The research proposed a new museum experience to provide tour guide content between visitor and machine through social approach.

In recent years, the growing interest in new technology amongst museum managers has been reflected in the deployment of multimedia devices in art exhibitions. These devices are viewed to be of critical importance to enhance the museums' role as educational institutions. They are used to support the interpretation of exhibits and to increase the appeal of museums to the public. Researchers and practitioners are exploring how these devices can be designed to increase the time visitors spend with exhibits, to provide visitors with additional information and to facilitate social interaction and discussion between visitors (Aoki et al., 2002; Falk, 2016; Vermeeren, 2016; Diamantopoulou and Christidou, 2016; Vermeeren et al., 2018;). Nowadays, technology plays an important role to support education, social interaction and narrative in museum. Moreover, the role of technology is changing with the role of museum.

2.2.3.1 Mobile

Mobile technology has been widely implemented in our daily life. Since it has been used to enhance museum visiting experience. Digital tour guide is one of the implementations

of mobile technology in museums. A study by Ciavarella and Paternò (2004) examines several personal guide systems in museum and discusses its benefits. The study points out that the personal guide provides significant benefits in enhancing museum experience such as increase attention among visitors and provides high quality information to visitors. In IRReal project (Butz et al., 2000), it uses a personal digital assistant (PDA) system with installed set of Infrared (IR) sensors in the museum environments. Once the visitors approach the museum artefacts, the system will present associated artefact information through audio, text and pictures. With the help of such personal guide system, visitors can personalise the tour contents.

In contrast to PDAs, smart phone applications are not limited to only audio, text and pictures (Rung and Laursen, 2012). Mobile learning (m-learning) is one of the concepts that have been implemented in museums. For example, Ceipidor et al. (2009) developed a mobile treasure hunt game where visitors solve puzzles by searching for QR codes in the museum. Lien (2015) developed an educational mobile game in museum to promote culture heritage but is limited to play only multimedia content.

With the rapid development of wearable technologies, wearable devices such as head mounted displays (HMDs) and smart glasses have been used in museums. Mobile devices have been extended to mobile virtual reality (VR) headsets, such as Google Cardboard and Samsung Gear VR (Anthes et al., 2016). The mobile virtual reality aims to provide users with ubiquitous and immersive experiences. For example, Theodorakopoulos et al. (2017) designed an AR experience in museum using the Google Cardboard. through mobile headset. Another research by Tan (2018) has confirmed the viability of supporting mobile VR over operational 4G LTE networks. The system implements cloud computing to offload graphical processing. However, the current 4G network are not enough to support the mobile VR everywhere and only support video output. Mobile headset provides potential interaction between different wearable devices and mobile device.

The following section describes two case studies of mobile applications in museums in more detail.

1. Artcode to Explore Artefact Relationship

Ghost Detector is a mobile game developed for children's education in the Cambridge Museum (Nilsson et al., 2016). The experimental mobile game integrated mobile technology and location technology to connect different parts of the museum. The design

of the game highlights the challenges associated with the development of location-based technology in public environment.

The research aims to attract new group of audiences previously not interested in visiting museums. Young children were identified as the user group. As the museum consisted of multiple buildings that spread across the city, the research project developed a ghost hunting game to encourage users to explore different parts of the museum (See figure 2.4).



Figure 2.4: Virtual characters representing different exhibits were animated and accompanied by messages to reflect the users' position and situation (Nilsson et al., 2016).

The Ghost Detector is developed with Bluetooth Low Energy technology (BLE) as part of an IoT platform. It allows mobile application to calculate the range of distance between BLE sensors hidden in specific artefacts and mobile users. Each ghost represents an artefact. As players walk through the museum space, the mobile screen will pop up a ghost and guide them to search for the artefact. The mobile game encourages the visitors to explore all parts of the museum. The study highlights how a seamful museum experience has the potential to attract new audiences, such as children, who are typically not interested in cultural or educational content.

2. Artcode to Explore Artefact Relationship

Visual markers such as QR code have been used to engage visitors to access digital content through their mobile phones (Schultz, 2013; Wein, 2014). Unlike QR codes, Artcode provides more freedom for users to customise the design of visual marker (See figure 2.5).

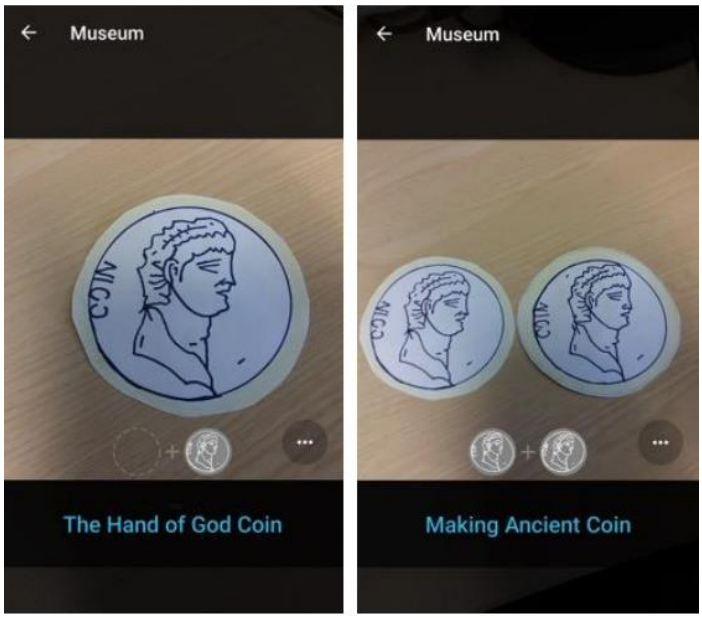


Figure 2.5:Artcode application (Ali et al., 2018)

An Artcode application has been developed to highlight relationships between artefacts (Ali et al., 2018). Participants could explore relationships between artefacts by simply placing cards on the map (revealing geographical relationships), or by physically configuring cards into appropriate groups or sequences and scanning them using the Artcode app. As shown in figure 2.5, each visual marker represents an artefact, while different combinations of Artcode will reveal a relationship between the artefacts. The study found out that the mobile visual marker encourages participants to explore the relationship between museum collection. it also highlights the benefits of support social interaction. The design encourages participants to collaboration and discussion.

2.2.3.2 Augmented Reality

L.Frank Baum proposed the first concept of Augmented Reality (AR) suggesting that an electronic device can combine data onto real life (Nelson, 2014). The implementation of AR can be traced back to 1957 when Morton Helig created a simulator called “Sensorama”. It consisted of a 3D screen environment within a machine constructed with sensors to blow wind and play sound to users (Sung, 2011).

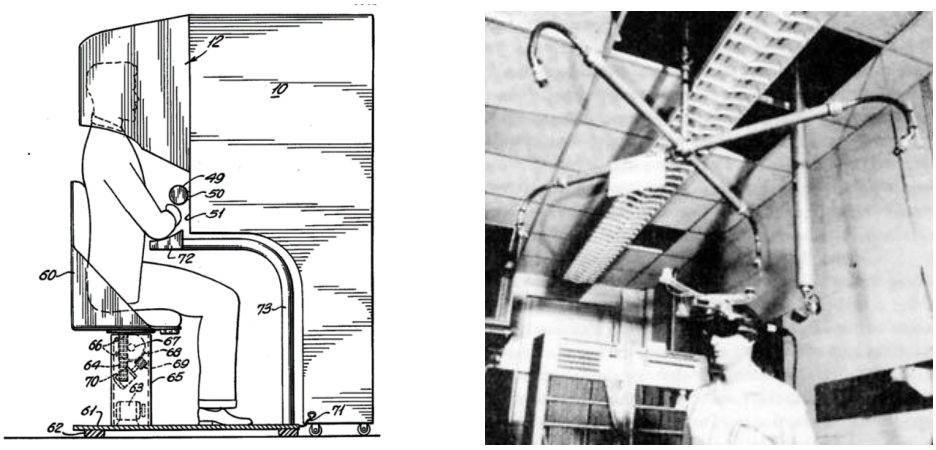


Figure 2.6:The design of Sensorama Simulator (left) (Sung, 2011), The first generation of HMD (right) (Nelson, 2014)

In 1966, Professor Ivan Sutherland invented the first HMD system, a milestone in the history of AR (see figure 2.6 (right)). However, the first generation of HMD system is difficult for people to wear due to it heavy weight. Although the system was restricted by hardware issue, it laid the foundation for AR, VR and wearable devices.

In 1999, Kato et al. released ARtoolkit to an open source community allowing researchers to create AR applications based on computers and webcams, reducing the cost and speed of AR development. In 2008, the first AR app is created by Mobilizy. The application is based on Android and it combines AR with GPS. The apps allows user using the camera to check locations around the world and the information of interesting point will show on screen. They also provide SDK called “Wikitude” on different platform, such as IOS and Symbian (Kipper et al., 2012).

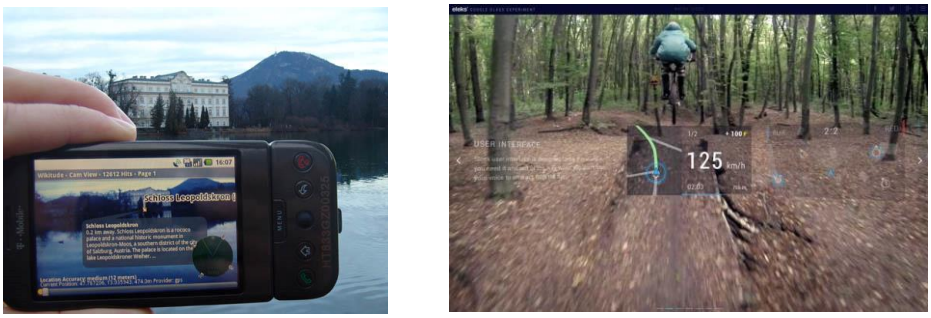


Figure 2.7:Wikitude AR Travel Guide (Kipper et al., 2012), First person view of Google Glass (Miller, 2015)

In 2012, Google launched an AR device called “Google Glass”, an HMD based on Andriod and connected to the internet. Microsoft launches HoloLens for research and

education purpose in 2015. One of the innovations with HoloLens is a user can directly model an object in HoloLengs and print it with 3D printer (Miller, 2015).



Figure 2.8:People modeling 3D object with HoloLens Invalid source specified from Microsoft website (2018)

Since, AR has been implemented in many fields and many development platforms have been introduced to support AR application development such as ARcore and Vuforia. There have two types of AR that can be supported by these platforms (Nelson, 2014):

- Location based Augmented Reality is one of most popular types of AR application implemented on smartphone. Location based AR can help users find out interesting place around them. This method works by detecting user location and adding related information on screen depending on the location of users (Harley et al., 2018). For example, Wikitude is an example of location-based AR application.

- Recognition based Augmented Reality also called Marker AR can recognise objects and provide associated information on the objects. In this method, any real objects can become a marker and the information will show on the marker, such as a picture, 3D model or video.

In conclusion, this section reviews the development history of AR and its different types. Recently, AR has been implemented to enhance visiting experience in museum. The following section describes several case studies of AR to improve museum experience.

1. AR for Museum Guide

Many cultural organizations have tried to use AR to enhance the visitor experience. Damala et al (2008) designed a mobile AR guide that uses QR code when scanned will provide information to users. Wu and Chang (2017) has also developed an interactive museum guide using AR. The app combined with GPS data will activate specific animation as visitors move to associated locations. The animation will be shown on screen (see figure 2.9). However, previous research shows that most AR applications are concerned with providing knowledge with little research focusing on interaction (Akçayır, 2017).

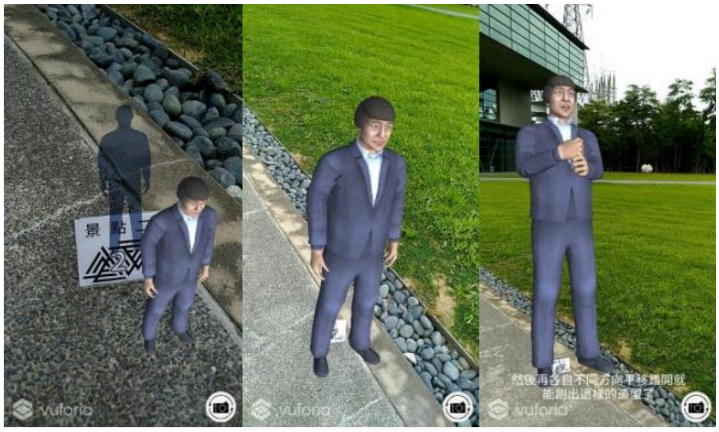


Figure 2.9:Animation of tour app (Wu and Chang, 2017)

2. Comparison of AR devices

Serubugo et al. (2017) presented a comparison study between wearable (Google Glass) and handheld (mobile phone) device to investigate which platform provides better engagement and performance as AR museum guide. The research aims to develop the AR museum tour guide to encourage interaction between visitors and artefacts.



Figure 2.10:The introduction function (left) and the game function (right) (Serubugo et al.,2017)

As shown in figure 2.10, the design of AR guide consists of several components which are interactive storytelling, tracking of artwork and superimposing of graphic. The interactive storytelling component provides narrative function to visitors. Visitors can explore details of artwork through the tracking of artwork and by superimposing graphic information (see figure 2.10). At the end of AR guide, it provides a small game to evaluate visitors' understanding of artwork.

The results of evaluation show that both smart glass and smartphone have potential to enhance museum experience. The researchers suggest future study could emphasis more game elements in AR museum guide.

3. MobileEye

Hammady et al. (2018) introduces MobileEye as a new user experience for museum visitors. It was developed with Bluetooth low energy as a location based and markerless AR. The AR visual content is shown to users through location-based data (see figure 2.11)..

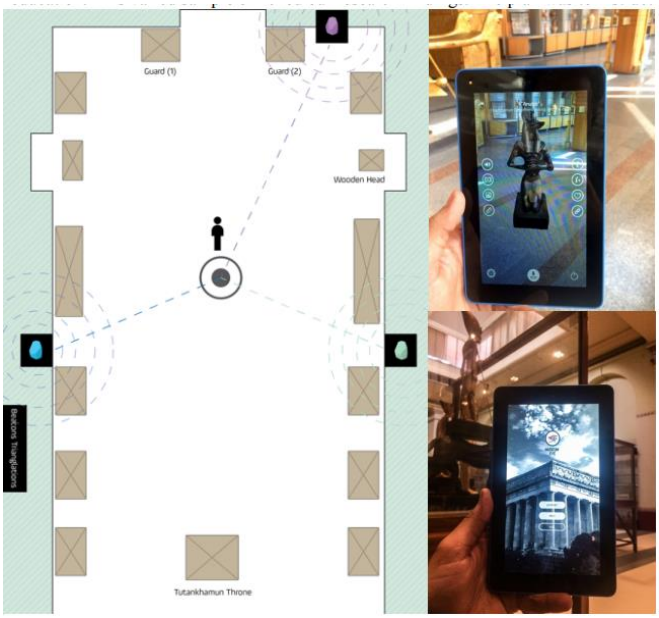


Figure 2.11:Placing IBeacons in the Egyptian museum's room(left). Testing MuseumEye at the Egyptian Museum in Cairo (Right) (Hammady et al., 2018)

As figure 2.11 shows, the MobileEye system has been implemented in Leeds museum and Egyptian Museum. The system implemented a Bluetooth low energy location-based product named IBeacons to locate user location. The AR application tracks the surface for marker and superimpose virtual artefact onto the surface. Users can rotate and zoom

the 3D model to check the details. The system was developed by Unity and ARcore demonstrating a new approach to design markerless AR application in museum. The result shows the potential of using AR guides in museums.

2.2.3.3 Virtual Reality

Sutherland (1965) presented his vision of the Ultimate Display simulating the real world in all available senses. A huge amount of research tries to achieve visions which is called the first wave of VR. Conn et al. (1989) defined the term Virtual Reality to combine the different concepts. In the past few years, a huge amount of input and output hardware and software have been developed in the second wave of VR. This section will examine the current status of hardware and software VR devices.

VR input devices consist of three types of devices which are Controller, Navigation Devices and Tracking (see figure 2.12). Each of the types have sub-categories. The following list gives the description of each type of input devices.

- Controllers: The controllers is most common input devices in VR design. The most original input devices are mouse and keyboard. In the latest generation of VR design, the controller are hand worn and provide discrete input in the form of buttons and continuous input by top-mounted joysticks or touchpads with additional 6 DOF tracking information. They may be wired or wireless.

- Navigation devices are key of input solutions that provides the illusion of moving through the virtual environment. The mechanic design of the device is similar to traditional treadmills. This kind of devices mostly still in research stages.

- Tracking: The tracking input devices divide into body tracking and hand tracking. Body tracking is mainly tracking and estimate the body posture to generate the input signal for VR system. The hand tracking also calls gesture tracking. This approaches mainly chosen a pre-programming gesture model to generate input for VR system.

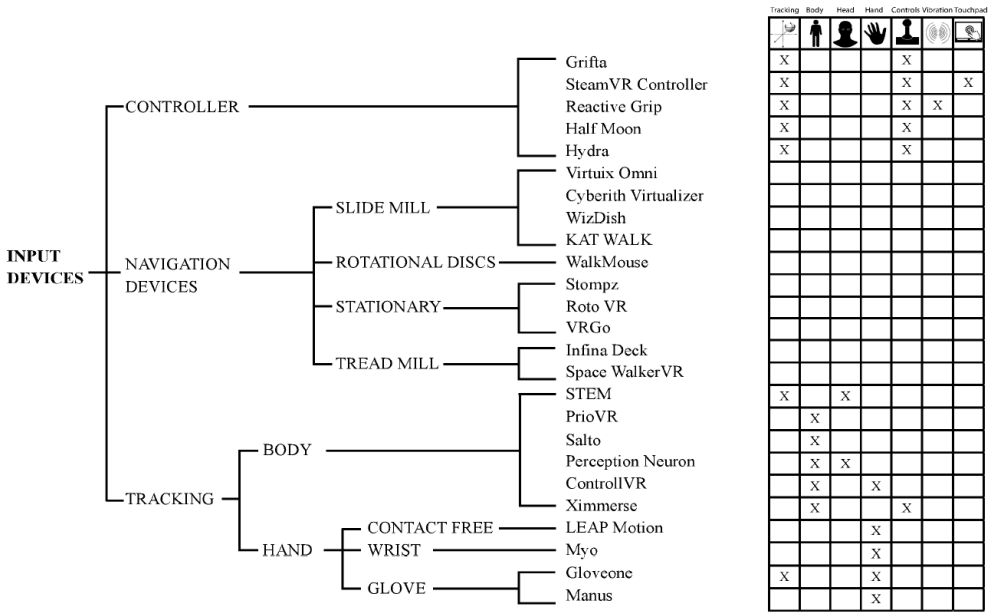


Figure 2.12:Input device of VR (Anthes et al，2018)

The output devices show the virtual world to users through visual, haptic and multi-sensory. The HMDs and monitors are the main technology to represent the visual display in today. The other two categories mainly provide haptic and multi-sensory feedback. Most of the haptic and multi-sensory technology still in prototype stages. Figure 2.13 shows the state of the art in VR output devices.

HMDs is a main way to provide VR experience. The HMD devices provide an immersive experience to users through virtual world. The HMDs have two subcategories which are mobile and wired. The mobile-based HMDs is based on mobile systems. The mobile application provides 360-degree movies or panoramas image to users. Due to the restriction of performance, mobile-based HMDs only support display visual content. The second big display category is wired HMDs. Some are equipped with cameras to allow for AR and can be used as video see-through displays, while others include eye tracking.

Additionally, haptic devices and multi-sensory devices are the future development direction of the VR system. The current haptic device mainly embeds motors or sensors to body worn devices to simulate the haptic feeling to users, such as shaking, temperatures. Multi-sensory devices give additional senses experience based on the displays and still under research stage.

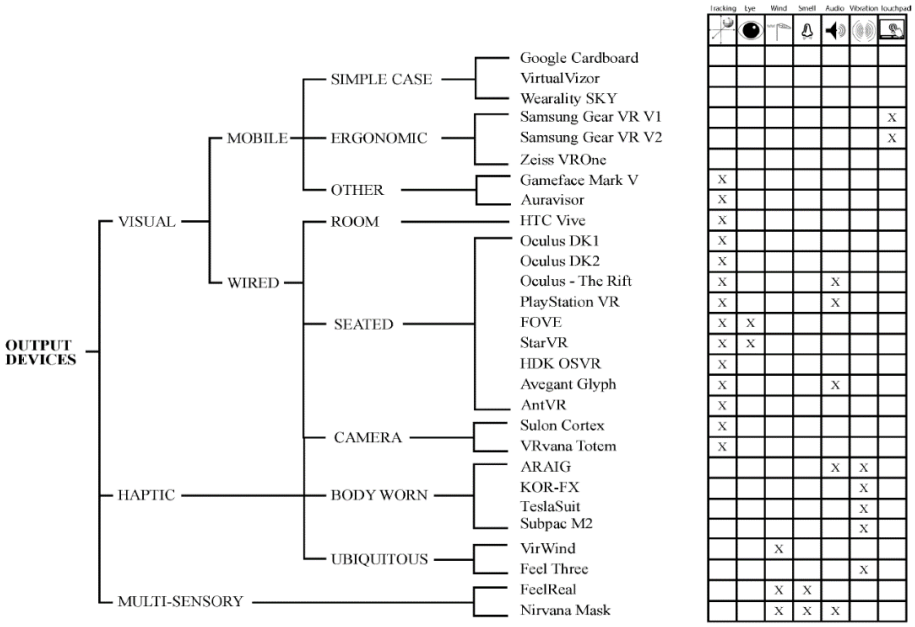


Figure 2.13:Output device of VR (Anthes et al.，2018)

In conclusion, this section reviews the state of art of VR and different types of VR devices. Recently, VR technology has been implemented to design immersive experience for museum. The following section will be described several case studies of VR to design for immersion in museums.

1. Viking VR

VR technologies enables museums visitors to experience places or objects (Schofield et al., 2018). Viking VR is a research project that helps visitors experience the sights and sounds of a 9th Century Viking encampment. The research teams designed an HMD setup to hold mobile devices (See figure 2.14). The researchers have used reconstructed scenes to help the public visitors learn about the past while also serving as a testbed for current archaeological thinking.

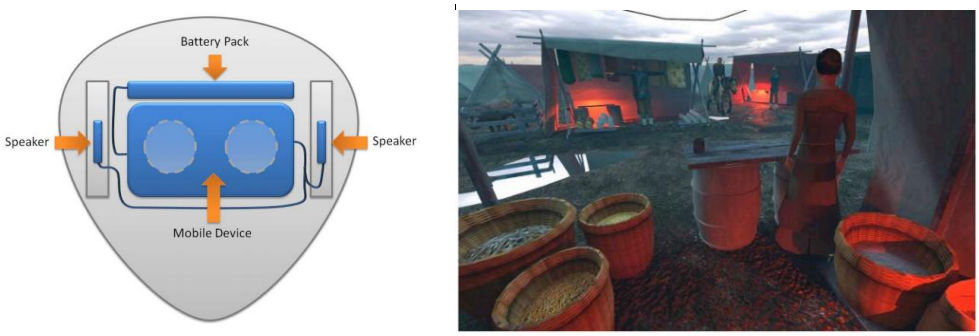


Figure 2.14:Viking VR headset and immersion design (Schofield et al, 2018)

2. Digiart

Anastasovitis et al. (2017) presented a VR project named Digiart to simulate cultural heritage worlds. The Digiart model was applied to three museums and evaluated by different participants. Digiart aims to develop new methods for automated 3D modelling and analysis of physical cultural resources and assets such as cultural heritage and archaeological sites, monuments, sculptures, beyond simple digital reconstruction.

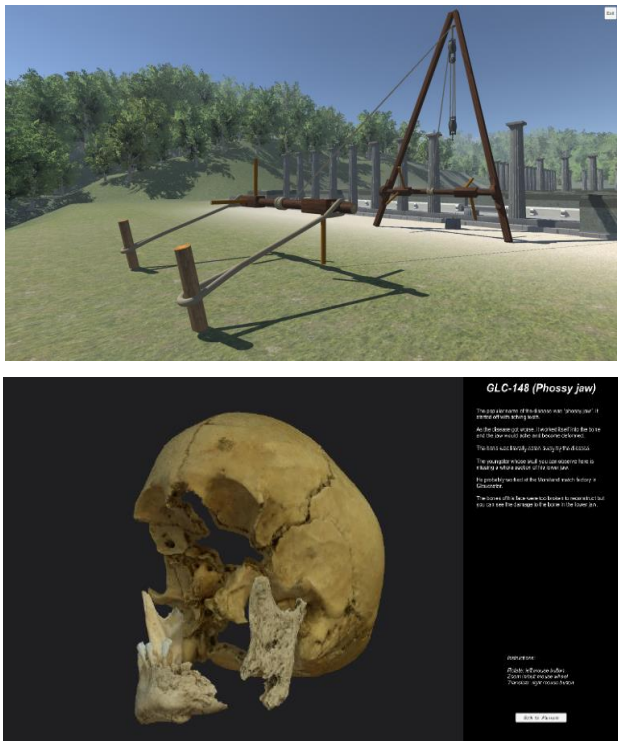


Figure 2.15:Using 3D environment to learn cultural heritages (Anastasovitis et al., 2017)

Digiart proposed a three-level development model for museum study. In the first step, the research team will scan artefacts through 3D scan technology. The second step identifies the interest point in virtual world. The interest point can be used to trigger information in third steps. The third step provides information of cultural artefact. As figure 2.15 shows, once players move to trigger point, it will trigger artefact page. In the artefact page, player can view the cultural information in 3D mode.

Overall, the authors developed a game development framework to transfer cultural knowledge through serious game. At the end of study, the result of evaluation shows that the immersive virtual worlds increase the effectiveness of digital educational games.

3. VR Touch Museum

Zhao et al. (2018) used an experiment to test if museum visitors perform better on “Presence” and learning achievements. In contrast to the above VR implementation, this research is conducted to reconstruct a VR system that combines both the virtual and the real world.



Figure 2.16:The VR Touch Museum. Left: User stands on an artificial grass surface while virtually outside. Right: The user feels the carpet when inside the ancient room (Zhao et al., 2018).

As shown in figure 2.16, the VR touch system provides a physical experience for players. When players move to different areas of the virtual world, they are allowed to experience the different material of floor. A comparison evaluation result shows VR touch system has better performance than the traditional VR system. Authors point out that VR system combined with tangible material holds the potential to be an attractive way to strengthen people visiting experience in museums.

2.2.3.4 Tangible User Interface (TUI)

In the 1990s, there were two research trends, one of groups argued that computers should be embedded into the physical world, which trend is known as Ubiquitous Computing. The other group claimed that computers should augment and enrich the real world with digital functionality (Shaer and Hornecker, 2010). Under the influence of Ubiquitous Computing and AR, Ishii and Ullmer (1997) published their vision of “Tangible Bits”. This vision of Tangible Bits is to provide a physical form to digital information and computation, facilitating the direct manipulation of bits (Ishii, 2008).

In past decades, the development of Tangible User Interface (TUI) covers different research areas. In the study of Shaer and Hornecker (2010), it classifies four research areas related to Tangible User Interface which are Ambient Displays, Tangible Tabletop Interaction, Tangible Augmented Reality and Embodied User Interfaces (Shaer and Hornecker, 2010).

Tangible tabletop interaction combines technologies of interactive multi-touch surfaces and TUIs by embedding the tracking mechanism in the surface (Shaer and Hornecker, 2010). The research of tangible tabletop is widely used to enhance the visitor experience in museums and exhibitions. The research team from Georgia Institute of Technology and Ryerson University presents a Tangible tabletop interaction system that supports cultural learning in the museum. The system is inspired by the Lukasa board, which is a memory board in Central Africa. Lukasa is a tool to create and share stories with each other. In the tangible tabletop system, tangible tabletop device assists visitors to learn and understand symbolic and non-linguistic mapping concept of Lukaca (Chu et al., 2015).

The Tangible AR is a type of AR interfaces that combines tangible input with an AR display or output. Tangible AR system shows augmented content through a marker placed on a physical object. In cultural heritage preservation, Tangible AR is widely implemented to link the past and present. For example, Madsen and Madsen (2015) present a Tangible AR system that allows visitors to view a restored scene of Castle Chapel Ruin. The visitors can compare previous castle environment from AR screen.



(A) (B)

Figure 2.17:Prototype of Embodied User Interface (Fishkin et al., 1999)

Overall, this section briefly introduces the concept of TUI, then it reviews three types of TUI. The following section describes several user case studies that implemented TUI to enhance museum experience.

1. MeSch Project

In recent years, the implementation of smart replicas using IoT is one of the trends in digitisation of museum artefacts (Vermeeren et al., 2016). MeSch is a project created by Sheffield Hallam University (Marshall et al., 2016) that uses 3D printing and IoT technology to create smart replicas to represent stories about museum artefacts. The following section describes its use scenario.



Figure 2.18:A single interactive case within the exhibition (Marshall et al.,2016)

The use of smart replicas was demonstrated in an exhibition titled “The Hague and the Atlantic Wall: War in the City of Peace”. The system is composed of two parts: smart replicas and multimedia display system. The smart replicas were made using 3D printing and embedded with RFID tags. The multimedia display system is used to identify smart replicas and play multimedia contents (see figure 2.18). The user can put smart replicas to RFID reader and multimedia content will display on the screen. The project supports a tangible interaction between users and the cultural heritage content.

2. Plankton Population

Ma et al. (2015) conducted a study that used a TUI and a multi-touch Graphical User Interface to support the exploration of a large scientific dataset at a museum exhibition. Plankton Population is a visualization system based on tabletop touch interaction screen.

It allows visitors interact with the virtual ocean world and explores the phytoplankton in different areas of the oceans. The system was developed as two versions, one tangible user interface version and multiple touch screen version. The research aims to clearly identify the strengths and weaknesses of tangible interfaces for tabletop interactions.

The exhibit allows visitors to explore the real scientific dataset and encourage them to explore the dataset. The interactive visualization system shows the distribution of four types of phytoplankton in the ocean. The visitors explore the phytoplankton through tangible rings or virtual rings. When visitors place the tangible rings or virtual rings at a location in the ocean on screen, it will show the different plankton with relative size. Moreover, it also allows visitors to access more information through interaction with tangible rings or virtual rings.

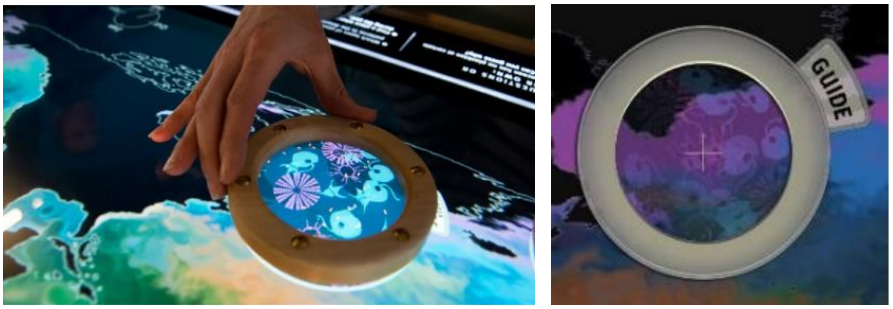


Figure 2.19:Tangible Rings(left) Virtual Rings (right) (Ma et al. (2015))

As shown in figure 2.19, it shows the two ways of interacting with the visualization system. The physical ring is embedded with three IR sensors. Visitors interact with the system through turning the rings. The virtual rings work like a normal touch screen. The result of evaluation shows the physical rings provides better user affordances through touching and physical manipulations. The tangible user interface helps to attract visitors. Moreover, authors believe TUI provides opportunities for people to talk and share.

3. Tangible Data Souvenirs

Petrelli et al. (2017) presented tangible data souvenirs as a tool to support physical museum visit and online digital experience. The system includes a tangible user interface tour guide system and online media system. The research aims to provide a new form of tangible souvenirs for visitors. The souvenirs consist of set of data where the data is dynamically generated by visitors log data.

As shown in figure 2.20, the tangible user interface tour guide system consists of one set of smart object and media system. The smart object was converted from museum artefacts. Each object was embedded with an RFID sensor. The smart object can be used to activate specific audio in museum tour guide system. The station data will be logged to smart object when visitors trigger museum data.



Figure 2.20:The use of a smart object at a showcase point (Petrelli et al., 2017)

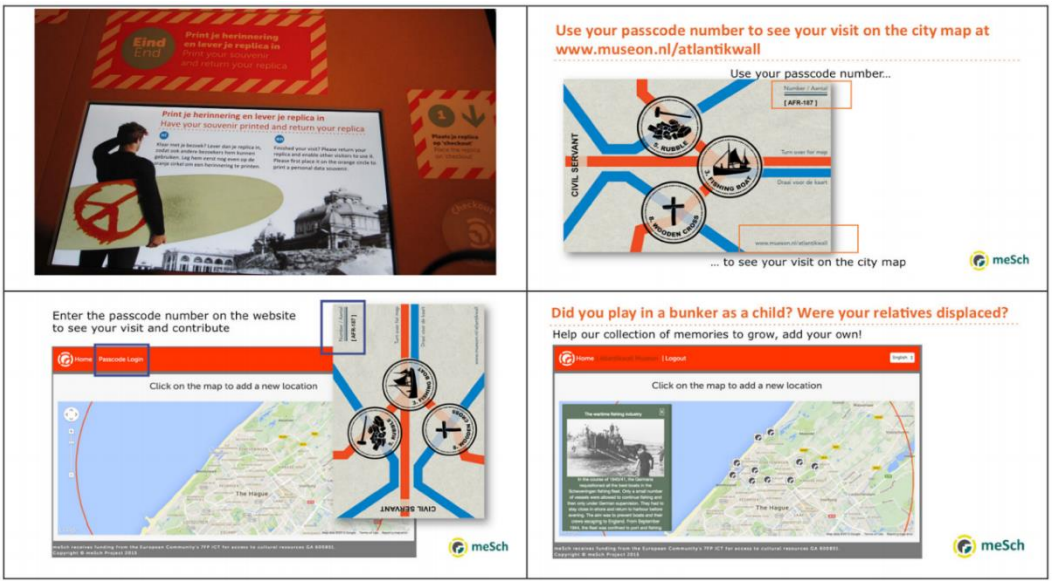


Figure 2.21:The implementation of souvenir postcard (Petrelli et al., 2017)

The online media system is prepared for post visit. Once visitors finish the tour, they need to return the smart object in return station. A postcard will be printed from return station. Victors can use the passcode number from post card to review the description of museum. As shown in figure 2.21, all the artefact information will be shown on a map.

In conclusion, the research found that visitors are interested to bring back the card as souvenirs rather than leave them behind at the museum. The research provides a solution to customise museum souvenirs for visitors.

2.2.3.5 Ambient Displays

Recently, ambient displays have been used to increase immersion in museum visiting experience. The ambient display aims to use ambient media for background interfaces with cyberspace at the periphery of human perception (Ishii and Ullmer, 1997). The research of ambient display is based on the purely graphical representations on monitors and wall displays (Shaer and Hornecker, 2010). Projection and projection mapping systems offer new possibilities for the display and visibility of works in public settings to create a range of potentials for the arts and cultural communities. Figure 2.22 shows an example of projection system to promote cultural imagination (Colette, 2016).



Figure 2.22:Stills, Digital Graffiti, Alys Beach, Florida 2015 (Colette,2016)

The projection mapping is one of the main techniques from the ambient displays. Projection mapping is a media art technique with tangible interface that projects images made by computer graphics to buildings or installations, projection mapping includes elements of graphic design and elements of visual expression as it has two-dimensional property. Projection mapping can appear as shape, layout and object and gives visual impression to viewers through multimedia contents. Projection mapping has been applied in advertising and digital art. This section will discuss digital research in public space and arts.

The projection mapping technique can be traced back to the late 1960s, where it was referred to as video mapping, augmented reality, or shader lamps. From 2001, projection mapping has been used by many artists in artwork, and groups such as Microsoft began experimenting with it as a means of technological advancement. After an object which will be projected is chosen or created, a virtual replica of the entire physical set up needs to be created (Yoo and Kim, 2014).



Figure 2.23:Projection mapping of dining project from Skullmaping website (2016)

As stated, digital art is the main implementation of projection mapping and it is one of best ways to draw attention from people. In recent years, digital art is affected by conceptual art that is an art movement, based on the “concept” or “idea” (Berna, 2011). For example, Shader Lamps enables the rendering of computer graphics onto real objects in three-dimensional space using projectors. Software developed for photographic processing, digital drawing, computer generated imagery and animated production have been widely used in the creation of digital artwork.” (Bandyopadhyay et al., 2001).

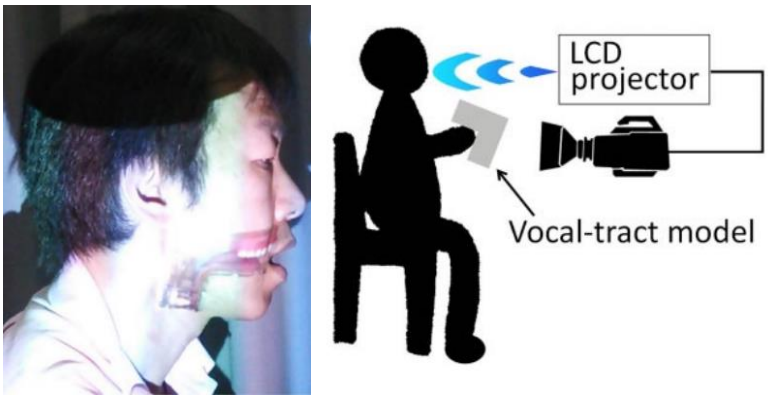


Figure 2.24:Schematic diagram and projection mapping effect (Arai and Uchida, 2015)

In recent years, the projection mapping extended to different domains and implemented with different purpose. For instance, Arai and Uchida (2015) proposed a projection mapping design for education purpose. The project used projection mapping technique to illustrate the human vocal tract and vocal-tract model with a flexible tongue (See figure 2.24). The research from Yoo and Kim (2014) designed an interactive video mapping system which is called Dynamic Room. The system proposed a new approach to help user mapping design and human. Figure 2.25 shows the interactive system where users

can select objects in room by handling joystick. Each object has different media content, such as raining and storytelling.

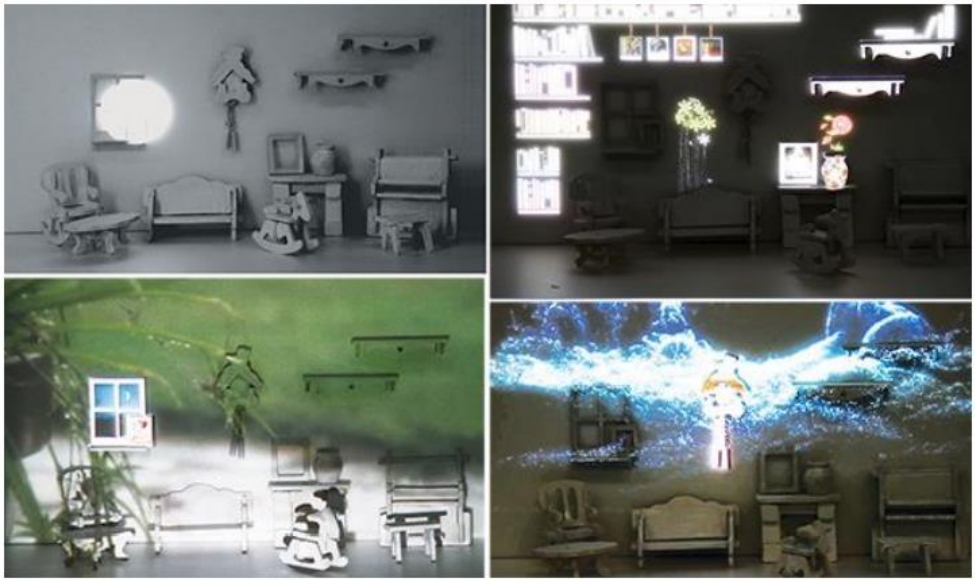


Figure 2.25:Dynamic Room scene images (Yoo and Kim, 2014)

2.2.3.6 Internet of Things (IoT)

The term "Internet of Things" (IoT) was proposed in 1999 based on its implemented RFID network on supply chains. The IoT suggests a world in which digitally identifiable physical objects are connected and able to interact with each other and the external world by exchanging data over the existing Internet infrastructure (Kuniavsky, 2016; McEwen and Cassimall, 2014). In recent years, IoT promises to revolutionise the way people interact with their environment and the objects within it by creating a ubiquitous network of physical devices (Li, 2017).

Thanks to the advancement in internet technology, IoT is now widely implemented in different domains as shown in figure 2.26. They include transportation and logistics, healthcare, smart environments, personal and social, futuristic (Atzori et al., 2010).

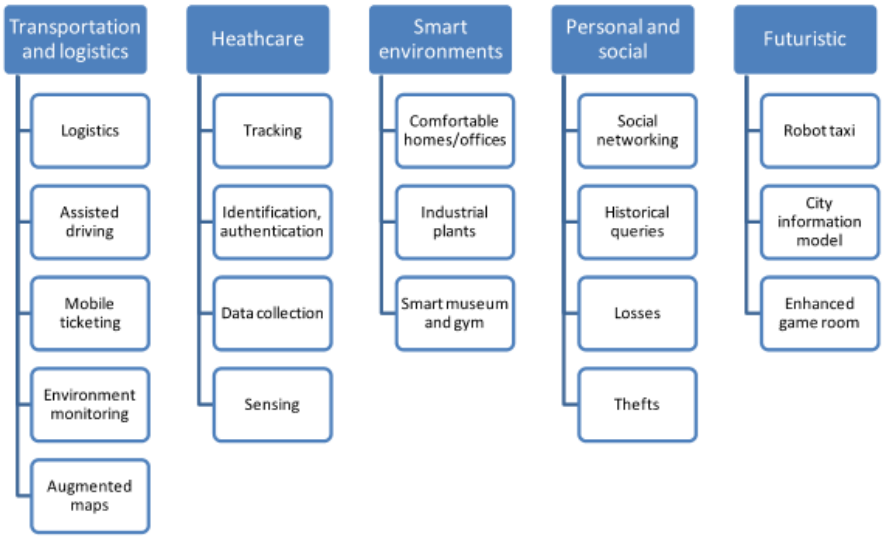


Figure 2.26:Applications domains and relevant major scenarios. (Atzori et al., 2010)

In a case study from Al-Fuqaha et al. (2015), it summarises current technologies, protocol, and application of IoT. IoT consists of six elements which are identification, sensing, communication, computation, service and semantic (see figure 2.27).

IoT Elements		Samples
Identification	**Naming**	EPC, uCode
	Addressing	IPv4, IPv6
Sensing		Smart Sensors, Wearable sensing devices, Embedded sensors, Actuators, RFID tag
Communication		RFID, NFC, UWB, Bluetooth, BLE, IEEE 802.15.4, Z-Wave, WiFi, WiFiDirect, , LTE-A
Computation	**Hardware**	SmartThings, Arduino, Phidgets, Intel Galileo, Raspberry Pi, Gadgeteer, BeagleBone, Cubieboard, Smart Phones
	Software	OS (Contiki, TinyOS, LiteOS, Riot OS, Android); Cloud (Nimbits, Hadoop, etc.)
Service		Identity-related (shipping), Information Aggregation (smart grid), Collaborative-Aware (smart home), Ubiquitous (smart city)
Semantic		RDF, OWL, EXI

Figure 2.27:IoT elements (Al-Fuqaha et al, 2015)

There are four types of IoT architecture mainly used in IoT development as shown in figure 2.28. The first type of IoT architecture is the structure of the early IoT systems. Currently, most of IoT systems use five-layer architecture.

The following lists explain different layers of IoT architecture:

- **Objects Layer:** Object Layer is the first layer of IoT architecture. The function of object layer is to collect and process data from sensors.

- **Object Abstraction Layer:** The object abstraction layer uses to receive and encrypt data from object layers. It will transfer sensor data to service management. The data can transfer through radio technology, such as 4G, Wi-Fi, Bluetooth.

- **Service Management Layer:** Service management also called Middleware layer, it used to receive data and process data to the application layer.

- **Application Layer:** Application layer can request data from sensors. The application layers cover numerous aspects, such as smart home, healthcare.

- **Business Layer:** The business layer uses to manage the information of the system. It used to convert sensor data to graphs and business models. This layer can commonly use to support business analysis.

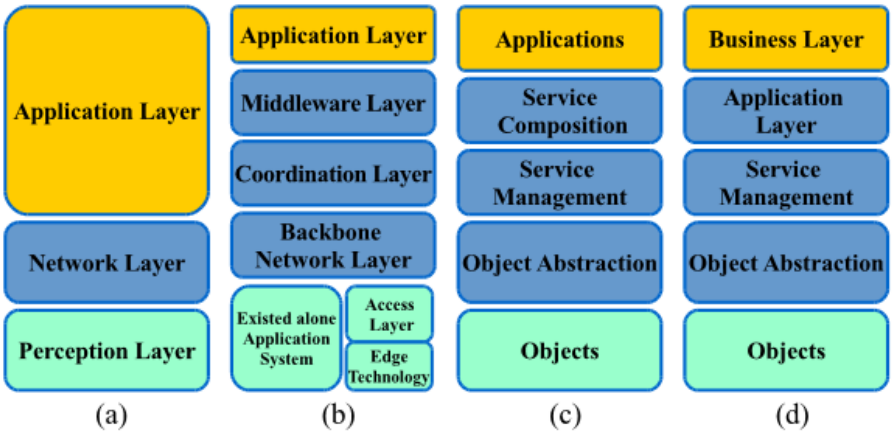


Figure 2.28:IoT architecture. (a) Three-layer. (b) Middle-ware based. (c) SOA based. (d) Five-layer. (Al-Fuqaha et al., 2015)

Although IoTs have been implemented to many domains, the interaction between IoT sensors and human is still limited in traditional ways. The interaction of IoT systems can be categorised as three main types:

- **RFID/QR code:** The system uses RFID or QR code to communicate with centre system, the server will process data and give feedback to the user through screens. Most of RFID/QR code interaction are applied to industry applications, such as supply chains, goods tracking system etc.

- **Voice Control:** The voice control is widely implemented in smart environments. The system normally integrates with smart speakers, such as Amazon echo, Google Home and Apple Siri.

- **Screen/mobile monitor:** The screen and mobile clients are the most common way to interact with IoT sensor network. This type of interaction is implemented with a system receiving sensor data. For instance, in mobile museum guide, once the sensor detects a visitor in a specified area, the mobile application will play videos or audios.

In most of the IoT implementation, the interaction between physical and human is heavily dependent on GUIs. However, more natural multimodal interaction are being implemented, such as spoken and gestural interaction (e.g., Siri, Amazon echo), some examples include mobile applications and embedded touchscreens for control of various functions (e.g., heating, lights, and energy efficiency) in environments such as homes and offices. In some cases, humans are an explicit part of the scenario, such as in those cases where people are monitored (e.g., children and elderly) by IoT devices.

Since most of IoT systems ignore the design of “things” in IoT, some researchers are beginning to focus on the design “Thing” for IoT, making it a popular topic in recent years. For instance, Li (2017) proposed a HCI concept of IoT design, to build interface for everyday objects. Currently, everyday objects do not have embedded electronic pieces and thus cannot support interactive applications. The research enhanced the sensing and interaction capabilities for everyday objects in an easy and unobtrusive way, unlike smart devices which are designed and built with touch-sensitive interfaces to enable interactive user experiences. The research invested a new RFID technology to interact with objects.

Another term called “smart object” represents a combination of TUI and IoT in recent years. Ghajargar et al. (2018) pointed out that smart objects are becoming a trend in our everyday activities. For example, Houben et al. (2016) developed an IoT sensor kits for ambient data display allowing users to use smart objects to interact with visual data. Another research presented by Mora et al., (2017) involved Tiles Cards, a set of 110 design cards and a workshop technique to involve non-experts in quick idea generation for augmented objects.

In conclusion, this section reviewed the concept and definition of Internet of things (IoT). Moreover, it introduces Internet of things system design architecture. In the end, it described several IoT concept that related to HCI research. The following section describes several IoT research related to museum.

1. IoT and Museum

In the research of Koreshoff et al. (2013), it provides a literature review of relevant HCI research related to IoT. The case study summarises 89 research papers and 93 commercial products. It also mentions trend opportunities and gaps between HCI and IoT.

The following list shows three types of HCI research relating to IoT:

1. **Evaluating for design:** This type of research directly uses data from sensors network. For instance, utilities is one of the domains implemented by IoT research. It uses IoT technology to reduce electric usages (Pierce and Paulos 2012).

2. **Exploring system:** The research uses IoT to observe data, such as to create an IoT system to track real-time information of train. The research of exploring system is more concern on creating a new interface or integrating different components with IoT technology.

3. **Exploring technical components:** The third type research aims to design new individual components, such as inputs, networks, middleware and agents, and data processing,

Table 2.1 shows current projects related to HCI and IoT aspect. The summary of result shows that most of the interaction between user and systems depends on mobile phone,

web application and tangible tabletop screen. Furthermore, IoT project is widely implemented in smart home and health care.

Table 2.1:Summary table of relevant IoT-related commercial efforts (Koreshoff et al., 2013)

	Category	Inputs and Sensor Types	User input interaction	How it interacts with you
Person-centric	**Sleep quality, EEG (Brainwaves)** - e.g. Somnus Sleep Shirt - *track movement and brain activity while asleep;* Melon - *track brain concentration levels*	Accelerometer, EEG	Wearing the device, mobile app	Alarm, web app, app notifications,
	Body tracking, Fitness tracking - e.g Leap motion - *body control for computers;* Basis bands - *Track fitness and body physiology*	Accelerometer, camera, electro-muscle sensors (EMG), thermometer, electrical conductance sensor, optical blood flow sensor	Movement, wearing the device, mobile app, buttons	Screen on object, web app, app notifications
	Weight tracking - e.g. Withings Wifi Bodyscale - *track weight and air quality over time*	Pressure, air quality	Standing on the scales, mobile app, web interface	Screen on object, web app, app notification, limited data interconnection
	Audio-visual logging, Event logging - e.g. Memoto - *continuous logging and transmission of activities* Lena Baby monitor - *tracking the words a baby uses*	Accelerometer, camera, microphone, magnetometer, GPS	Wearing the device	Screen on object, web app, app notification, limited data interconnection
Home-centric	**Home appliances, Lighting** - e.g. LG SmartFridge - *adjusts temperature based on contents, orders food, suggests recipes;* iRobot Roomba – *automatic vacuuming;* Lifx – *internet-controlled light globes*	RFID, NFC, contact, thermometer, contact sensor, infrared sensor, radio-frequency sensor, light switch, third party data sources	Screen on object, mobile app, using the object, buttons	Screen on object, app notification, environment alteration, data interconnection,
	Home security, Locks - e.g. ismartalarm - *automatic home monitoring;* Lockitron - *presence activated automatic house locks*	Contact, motion, video, microphone, twist sensor, buttons	Mobile app, movement, object use	Alarm, app notification, phone call, environmental alteration
	Utility measurement, Environmental awareness - e.g. WattVision - *tracking electricity, water, gas and internet usage;* Nest thermostats - *adjust temperature based on room occupancy*	Thermometer, motion, light, buttons, inductive clamp, microphone, router	Utility usage, mobile app, screen on object, web interface	Environment alteration, screen on object, web app, limited data interconnection
	Garden monitoring - e.g Botanicalls - *monitor plant health to trigger watering or alerts*	Electrical resistance, light meter	Watering the plant	App notification, limited data interconnection
	Frequency tracking, Location tracking - e.g. GreenGoose - *stickers that track the duration of object usage;* BiKn Tags – *attachable tags that allow object and person tracking*	Accelerometer, Zigbee, GPS	Moving the object, movement, web interface	App notification, web app, limited data interconnection
	Reminders and Notifications - e.g. Vitality GlowCaps - *bottle caps that remind you to take your medicine*	Accelerometer, contact, third party data sources	Moving the object	Screen/lights on object, app notification, phone call, SMS, limited data interconnection
	Configurable platforms - e.g. SmartThings - *components that are built to be reconfigured based on the task needing completion*	Accelerometer, motion, moisture, presence, contact, temperature, power	Moving the object, using objects, movement, mobile app	App notification, web app, environment alteration, data interconnection

Due to advancement in IoT technology, the creation of smart museum has become a trend in museum design. Currently, smart environment and Indoor location service are widely implemented in a smart museum. Smart environments use sensor networks to control lighting, temperatures in museums. Indoor location service is often used with the mobile tour guide.

In the research of Chianese and Piccialli (2015), it presents a museum tour system with IoT technology. The system is implemented in an exhibition with 270 sculptures. The system consists of three components which are the mobile application, SLAVE Nodes, and server nodes. Firstly, SLAVE nodes are used to communicate with the mobile application. Secondly, the mobile app can calculate user location by getting data from SLAVE Nodes. Finally, mobile app downloads multimedia content from Server nodes.

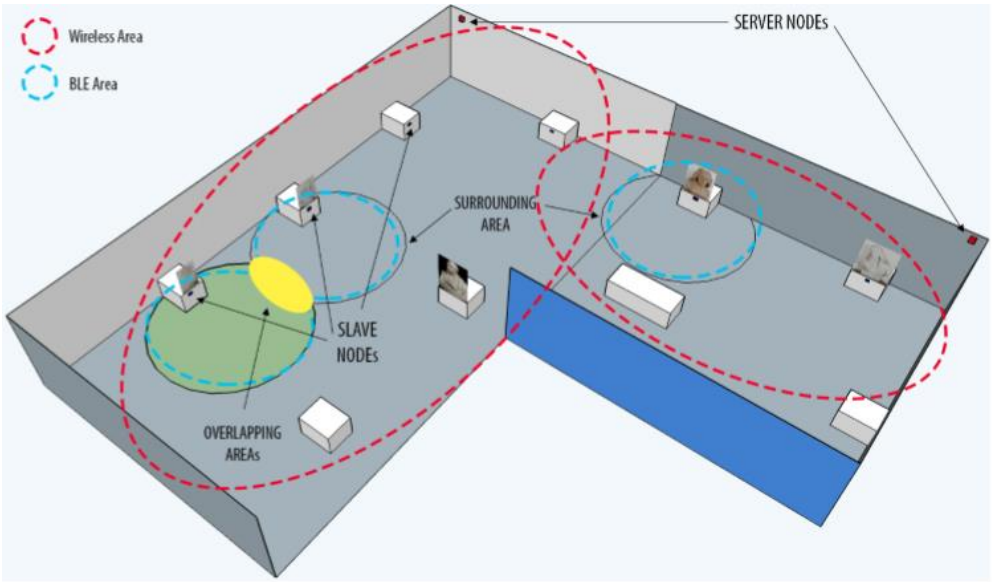


Figure 2.29:A simple schematic layout of a museum (Chianese and Piccialli, 2015)

In conclusion, IoT is widely implemented in transportation and logistics, healthcare, smart environments, personal and social, and futuristic settings. In HCI applications in museum domain, most of the current research projects only involve interaction with users through a mobile or web application. The current implementation of museum more concerned on administration and location-based services. There is very little research implement IoT to enhance museum experience. Along with the 5G development, the IoT technology has huge potential to increase the museum experience.

2. Amuse

Wecker et al. (2015) presented a research to associate museum visits to outdoor cultural heritage activities. Amuse is an application to bridge a perceived gap between the museum experience and subsequent experiences at cultural heritage sites by allowing museums to serve as a gateway to other cultural heritage experiences. The design of Amuse operated in the tower of David which is located in the old city of Jerusalem. The mobile guide implemented in two scenarios which are museum and cultural heritage. In the museum, mobile app provides guide information and analysis of visitor behaviours. In cultural heritage site, the mobile application provides information of old building.

The Amuse aims to develop a mobile guide birding the museum and cultural heritage sites. The Amuse mobile guide is different from traditional mobile guide. The traditional mobile guide apps only provide artefacts information to users. In the case of Amuse, the mobile guide analyses visitor behaviours and movement to identify their interest in museum. When visitors start their tour in the old city, the mobile guide will generate a suggestion list for them

based on the analysed result. The mobile guide application also provides a notification function. when visitors in the area near a site that they may be interesting, the notification will give information about the site.

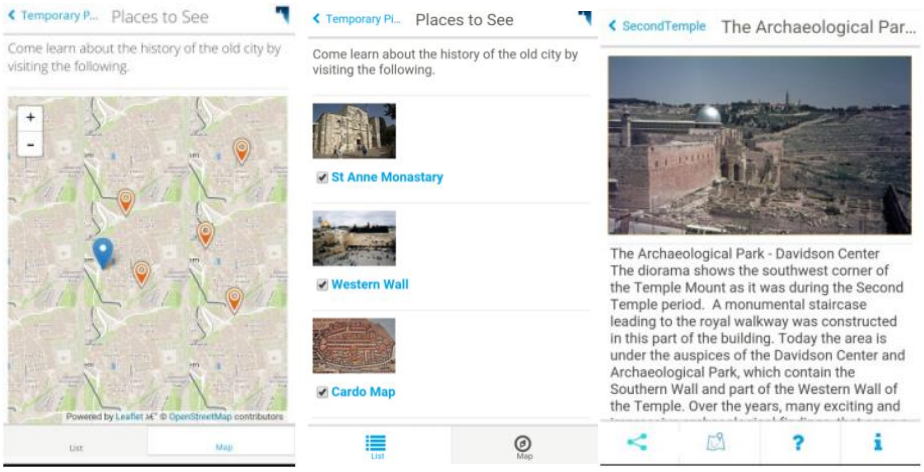


Figure 2.30:Amuse museum guide app (Wecker et al., 2015)

In the case of Amuse, the mobile guide book provides customised experience for visitors. The mobile guide book analyses interest and behaviours to generate suggestion guide tour list for them. Moreover, the notification of application reminds the visitors when they are near the interest cultural heritages sites. The implemented museum guide book shows the potential to give a better museum and cultural heritage site experience to visitors.

2.2 Existing Toolkit

2.2.1 Software Toolkit

This chapter reviews existing software toolkit related to IoT and game development, which are the focus of the thesis work. Due to increasing software complexity, software toolkit has been developed to increase productivity and ease of use in software development. Traditionally, the integration of hardware and software development, especially in the development of IoT systems require software engineers to have hardware skills and knowledge. Game development may also require a lot mathematical calculation and graphic rendering. Therefore, one of the solutions is to encapsulate the communication component as a software toolkit for the developers.

2.2.1.1 RapIoT toolkit

Gianni et al. (2018) presented a software toolkit that helps the prototyping of IoT systems by integrating a set of infrastructure service called RapIoT. The development of IoT system prototypes is a complex task for software developers because it requires hardware development skills and deals with multi-layered hardware and network infrastructures. The RapIoT aims to help non-experts develop collaborative IoT applications between different IoT sensors. As shown in figure 2.31, the RapIoT toolkit bridges the IoT device and application by handling input and output data.

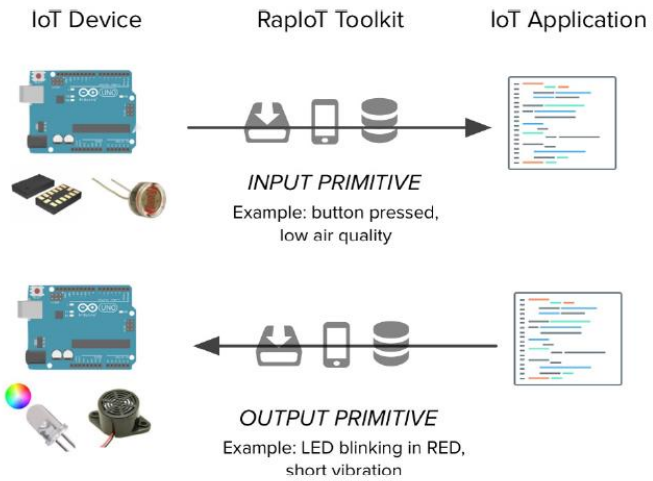


Figure 2.331:Input and Out primitive (Gianni et al., 2018)

In the technical design of RapIoT toolkit, it consists of three layers. Figure 2.32 shows the architecture of RapIoT toolkit. The following list describes the three layers of the toolkit.

- Embedded layer: Embedded layer based on a microcontroller board call Arduino. The Arduino come with a development Arduino IDE, it allows users to develop their own IoT prototype. This layer includes an Arduino based library which call RapEmbedded, it handles IoT sensor data through Bluetooth protocol.

- Gateway layer: The Gateway layer is a cross platform mobile app call RapMobile. The RapMobile app play a role to bridge embedded layer and server layer. The mobile connects Embedded layer (RapEmbedded) device through Bluetooth protocol and the app reroute the sensor data to Server layer (RapCloud).

- Server layer: The server layer developed a Software as a Service (SAAS) platform called RapCloud. Rapcloud includes an online IDE based on JavaScript library and web-based configuration utility. The users need to register account from the website and configure the IoT device connection from RapCloud. The server developed with a broadcast-based function to publish device data to IoT application.

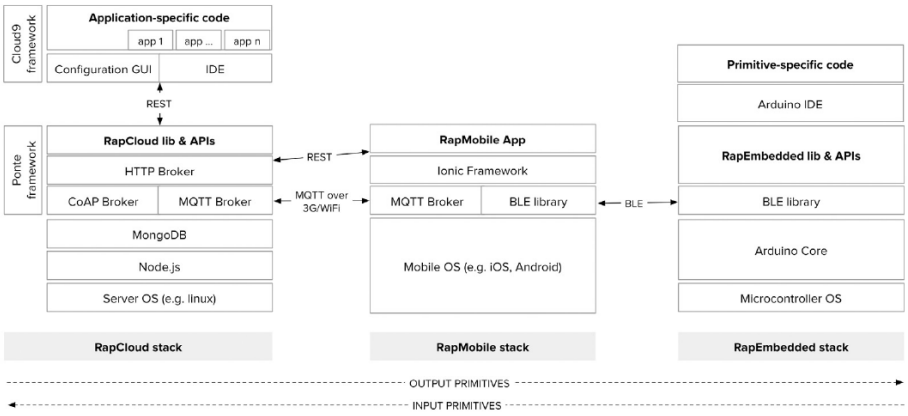


Figure 2.332:The architecture of RapIoT toolkit (Gianni et al., 2018)

The implementation of RapIoT can be deployed in four steps. In the first steps, the user needs to choose the types of sensors and purchase a ready-to-use RapIoT version IoT device. The device comes with a pre-installed RapEmbedded library. The user can launch the device. In the second step, user registers on Rapcloud website and configures the input and output of IoT devices. In the third step, the user needs to login to the mobile application and connect to a restricted IoT device. Finally, they can start to build the logic of IoT application from broadcast-based json data.

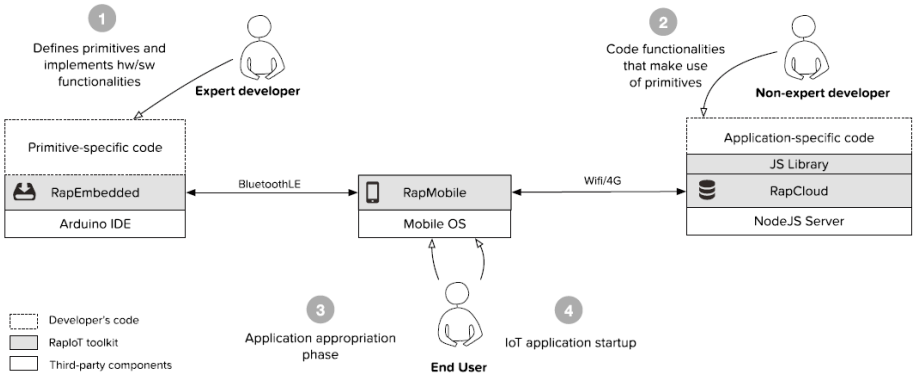


Figure 2.333:The RapIoT toolkit, development and deployment process (Gianni et al., 2018)

In summary, RapIoT holds a huge potential for rapid IoT application development. The design of RapIoT helps non-experts to develop application with IoT hardware, but the RapIoT also has limitation on connection issue. The device must publish data through a mobile application. Network latency can be a significant factor that affects the toolkit performance. For future development, there are lots of rooms to improve the architecture of such toolkit.

2.2.1.2 IoTLink

Pramudianto et al. (2014) presented an IoT toolkit named IoTLink. IoTLink is a rapid prototyping development kit for the manufacturing industry. The development kit is based on a Model-Driven Development approach. The Model-Driven Development approach develops software with a pre-design model. The user only needs to drag and drop the model through visual tools. The IoTLink system implements a high-level model to assist inexperienced developers to develop IoT application and services through visual tools. As shown in figure 2.34, the visual tools combine different models to represent "Things". The model provides a translate function to convert model code to Java code.

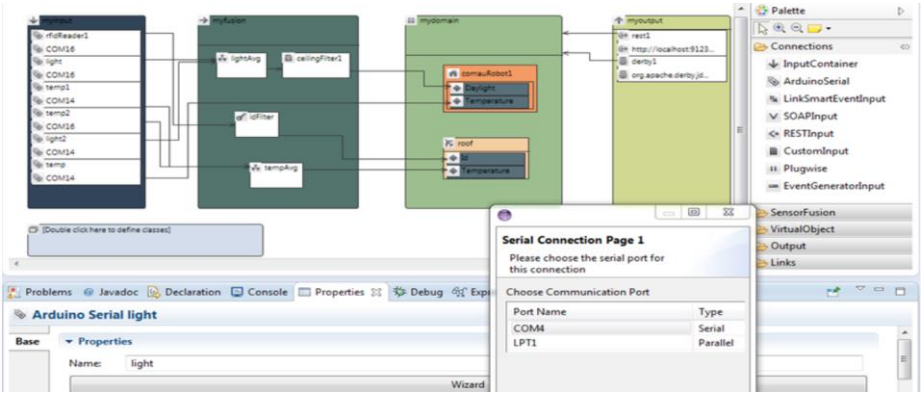


Figure 2.334:The iteration of IoTLink (Pramudianto et al., 2014)

The IoTLink system is developed using Eclipse, a Java development platform. The IoTLink provides a graphic user interface for the development of IoT hardware. The following list describes the IoTLink components.

- Arduino is a hardware used for rapid hardware prototyping. In IoTLink system, the sensors are connected through Arduino.

- Resful API provides a simple and light way to transfer data. Users transfer data through a simple URL and Json format.

- SOAPInput is a service to connect server and web application, it widely deploys in enterprise applications.

- OPCCclient is a component to connect industry device and server. The components are widely implemented in factories.

- MQTT broker is a communication standard for IoT application transfer data. The portal allows the device to communicate with low bandwidths.

In summary, the IoTLink system provides a Model-Driven approaches to develop IoT prototyping in industry. The design of IoTLink follows a human-centred approach to build visual tools. The IoTLink system allows inexperienced developer to use a GUI programming tool to build IoT systems. In a controlled experiment, development using IoTLink was 42% faster than traditional programming approaches.

2.2.1.3 Unity3D Engine

Along with the evolution of game technology, many game development platforms have become available to game developers. Unity3D is a game engine simplifies the development process for programmers. It integrates video games, architectural visualization and real-time 3D animations in the game development. Its editor runs on Windows and Mac OS X platforms. Though it runs on only two platforms, it has the ability of developing applications for multiple platforms to include Windows, Windows Phone, Mac OS X, iOS, Wii, Linux, Android, and Web Player with a software development kit (SDK). There are various plugins to export the application to different web players such as Flash Player.

Unity3D consists of various components. The review from Patil and Alvares (2015) summarises the main components of unity3D editor:

- **Render System:** The render system of Unity3D integrated different graphics engine for different platforms. The Direct3D support Windows development. The OpenGL support Mac, Windows and Linux. The OpenGLES support Android and IOS. Moreover, the render system also supports proprietary APIs like Wii, Xbox etc. The unity3D game engine

support bump mapping, reflection mapping, dynamic shadows render (Patil et al., 2015).

- **Scripting:** The development languages of Unity3D engine are C# and javascript. The scripting is built on Mono, an open-source .NET framework. The script edits by MonoDevelop IDE.

- **Networking:** The unity3D engine includes a networking component to help developer build multiplayer games. This component allows Real-time Networking, Remote Procedure Calls, Backend Connectivity.

- **Asset Store:** The Asset store includes in Unity3D ecosystem. The Unity3D generate a file type call unity package. The Unity package allows developers to develop the game material or plugin for the editor and compress it as package file. Nowadays, the unity asset store consists over 7000 packages. The package includes 3D models, textures and materials, particle systems, music and sound effects, tutorials and project scripting packages, editor extensions and online services.

In recent years, cloud computing and mobile development are becoming popular. The benefits of Unity3D engine are it makes realistic game world and the Input components allows input device developer to build a plugin for the game, such as to include joystick and VR sensors. The physical engine and AI module of Unity shows its high performance, flexibility for game development. In short, the Unity3D game engine is a powerful game development tool for future generation game development.

2.2.1.4 Leap Motion

Leap Motion Controller is one of devices that connect to a PC through USB port. The device implements InfraRed (IR) to process real-time images to define the position of objects in a small space. The device comes with a system to sense hand and finger movements in the air above the Leap Motion controller. The sensor software analyses the object position and generates position data for future development. Figure 2.35 shows the design of Leap Motion Controller. The device can detect hand position data in an inverted pyramid area on the device. The effective range of device from 25 to 60 millimetres above the device.

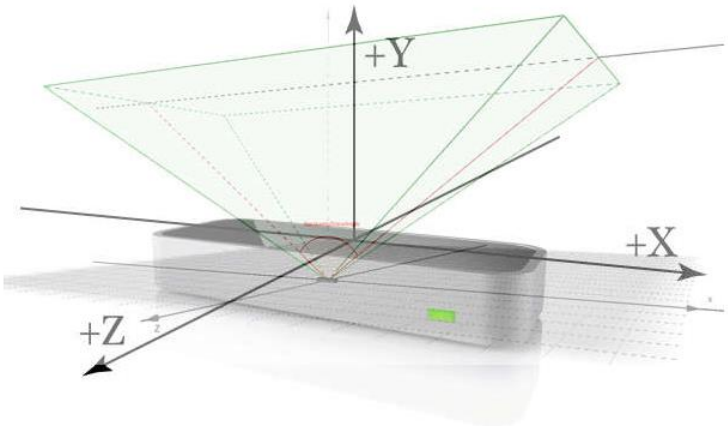


Figure 2.335:the detection area of Leap Motion Controller (Khelil et al., 2016)

The following figure 2.36 shows the development process of Leap Motion Controller. The Leap Motion Controller needs a pre-game environment consisting of Unit3D, C# and Leap Motion SDK. The Leap Motion SDK is a set of package file that can be loaded to Unity3D. In the Data collection, the SDK helps to analyse the data from Leap Motion device. The analysis provides a base “x,y,z” position data to developers. Figure 2.37 shows the position data from hands. The feature extraction and classification can be designed by developers. In the end, the hand gesture recognition depends on an algorithm developed by programmer.

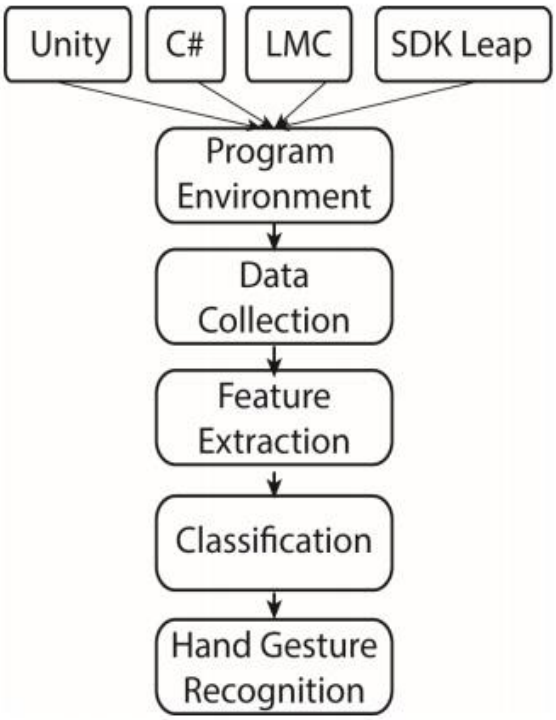


Figure 3.336:The development process of Leap Motion Controller (Khelil et al., 2016)

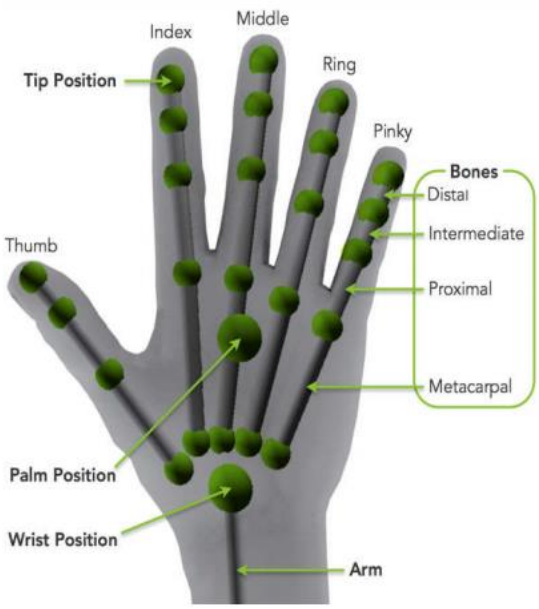


Figure 2.337:Palm and tip positions given by the Leap Motion Control (Khelil et al., 2016)

In summary, the Leap Motion controller provides a quick development solution for Unity3D. The gesture recognition device shows the potential for AR/VR development. The design of Leap Motion reduces the development process and helps software developers to build interaction game/application between physical and virtual world.

2.2.2 Hardware Toolkit

There are many hardware-based toolkits that are designed for the development of IoT systems. This section describes the electronic board-based toolkit and module-based toolkit.

2.2.2.1 Development Board

The IoT system requires highly dynamic and radically distributed networked system composed of large number of sensors (Maksimović et al., 2014). The sensors network needs powerful hardware for computing and communication. Therefore, the use of small, powerful, cheap and flexible computer hardware become popular for IoT development.

Maksimović et al. (2014) describes the most common development board that available on the market:

Raspberry Pi is a project introduced in the UK in 2012 under Raspberry Pi foundation. The first version of Raspberry Pi aimed to build a low-cost computer motherboard for school children and promote basic computer programming skills. Nowadays, Raspberry Pi is widely implemented in various research areas. Raspberry pi software can also be programmed in different languages, such as C#, Python and C++.

Raspberry Pi comes with a Linux based OS. The hardware comes with GPIO (general purpose input and output). The Raspberry Pi has 26-pin GPIO port for sensors extension (Figure 2.38). The GPIO pin allows developers to connect sensors through wires. The Raspberry Pi also supports the mainstream digital inputs and output protocols, such as 12C and SPI. It provides the possibility to developing IoT application with various electronic components.

P1							
<50mA	3V3		1	2		5V	
BCM GPIO00/02	SDA0/1	8	3	4		5V	
BCM GPIO01/03	SCL0/1	9	5	6		GND	
BCM GPIO04		7	7	8	15	TX	BCM GPIO14
	GND		9	10	16	RX	BCM GPIO15
BCM GPIO17		0	11	12	1	PWM0	BCM GPIO18
BCM GPIO21/27		2	13	14		GND	
BCM GPIO22		3	15	16	4		BCM GPIO23
<50mA	3v3		17	18	5		BCM GPIO24
BCM GPIO10	SPIMOSI	12	19	20		GND	
BCM GPIO9	SPIMOSO	13	21	22	6		BCM GPIO25
BCM GPIO11	SPI SCLK	14	23	24	10	SPI CE0 N	BCM GPIO08
	GND		25	26	11	SPI CE1 N	BCM GPIO07
P5							
<50mA	3V3		2	1		5V	
BCM GPIO29	SCL0	18	4	3	17	SDA0	BCM GPIO28
BCM GPIO31		20	6	5	19		BCM GPIO30
	GND		8	7		GND	

Figure 2.338:Raspberry pi GPIO pins (Maksimović et al.,2014)

Arduino is an open-source hardware and software project. Arduino development board is another famous IoT development board available on the commercial market. The project was launched in 2005 with the aim of building a solution to interact with different sensor and machine more efficiently. The board design reads data from the sensor and sends it to a computer or machine. The design of the board consists of a set of digital

and I/O pins. Arduino is running without OS and directly gets its command from Arduino IDE. For programming, it supports Java, C and C++ languages.

The Arduino is based on a simple microcontroller. The development process of Arduino is more complex. The development of Arduino depends on Arduino Integrated Development Environment (IDE). The developers need a computer to connect Arduino through USB cable. In the next step, the Arduino can be programmed and deployed using the Arduino IDE.

The following table 2.2 shows comparison between Arduino and Raspberry Pi:

Table 2.2 Comparison between Arduino and Raspberry pi

	Arduino	Raspberry Pi
Price	30USD	35USD
Size	7.9*1.9*6.4cm	8.6*5.4*1.7cm
Memory	0.0002MB	512MB
Original OS	NO	Linux
Multitask	No	Yes
Flash	32KB	512MB

In summary, Raspberry Pi and Arduino are the most common development board for IoT application and prototyping. Table 2.2 shows the comparison between Arduino and Raspberry Pi. The development of Arduino is more dependent on the IDE. Developers do not need any setup for the hardware, but the performance of Arduino is weak. It means the developer needs to spend time to optimise the program. Its performance also limits the numbers of input sensors that it can support. In contrast to Arduino, Raspberry pi comes with an original OS and has a powerful performance to allow developers to build IoT applications with huge data and input/output devices.

2.2.2.2 Little Bits

As the implementation of electronics is becoming more common, there is a growing number of Do-It-Yourself (DIY) industries and open source developments (Bdeir, 2009). LittleBits is an opensource library of discrete electronic components pre-assembled in tiny circuit boards. LittleBits aims to explore a new electronic solution to reduce the development time for electronic products. The solution should help non-experts to develop electronic products, such as designers and artists. In order for LittleBits to be

more flexible, the researchers divide the electric circuits to many modules. The idea is to create an electronic product by combining different modules such as coin cel battery, slide switch, light touch switch and LED. The different modules will connect with magnet. Figure 2.39 shows the different components of LittleBits. LittleBits library consists of three types of modules: Power(P), Components(C) and Wire(W).

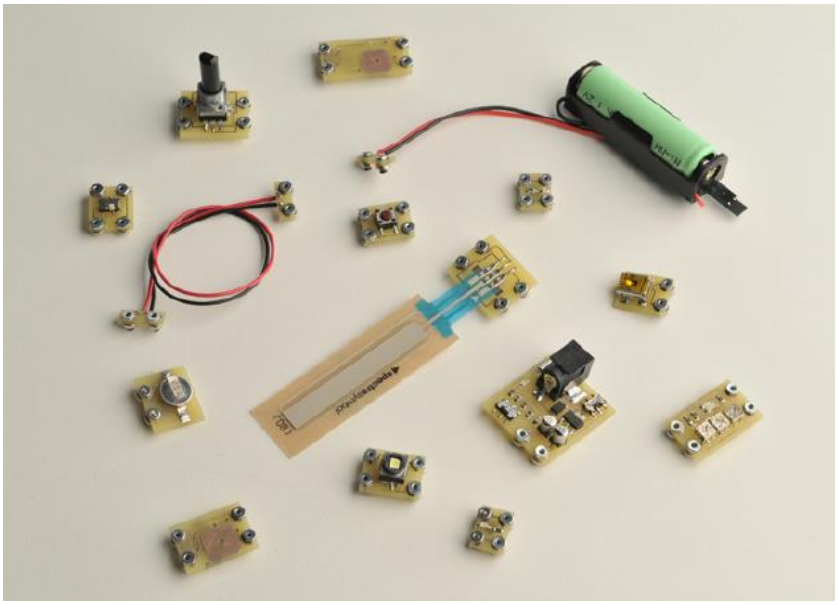


Figure 2.339:LittleBits (Bdeir, 2009)

In summary, LittleBits provides a plug-and-play solution for non-experts to develop interactive prototypes. However, LittleBits does not support the IoT application with the virtual world, such as mobile application and game world.

2.2.3 Card-based Design Tool

Brainstorming is often described as a way to generate creative ideas for solving particular problems (Novak,1997; Paulus,2000). An advantage of brainstorming is to allow people with multiple areas of expertise to come together to produce a joint effect that is greater than the sum of the individual parts (Eckerson,1988). Solutions may present themselves in such an environment that would not be evident to individuals working alone on the same problems. However, researchers have found that using traditional brainstorming has a number of disadvantages. For example, early ideas tend to have disproportionate influence when people fixate on one idea, instead of coming up with truly unique thoughts (Jansson and Smith, 1991). Developing an effective creative brainstorming process can prevent this.

Recent studies on card-based ideation tools have shown that they are indeed effective for brainstorming (Vaajakallio and Mattelmäki, 2014). The card-based ideation tools resemble card games, possessing game-like rules ranging from the way they structure card draws, turn-taking, playing and discarding cards to randomly revealing them (Wetzel et al., 2017). They are useful for bridging the gap between design theories and design practices (Stout, 2013), help describe complex concepts to non-experts, encourage discussion and shared understanding between stakeholders and designers (Lucero and Arrasvuori, 2010; Mora et al., 2017; Rubino, 2015) and help people “think out of the box” (Mueller et al., 2014), which can improve design outcome (Chen, 2011). Furthermore, card play adds game mechanics helpful in engaging multiple stakeholders in a playful manner and ensuring that a design space is investigated from different points of view (Brandt and Messeter, 2004; Vaajakallio and Mattelmäki, 2014).

This section reviews some existing card-based ideation tools for game and IoT ideation).

2.2.3.1 VNA Card

Kultima et al. (2008) developed the VNA Cards for game ideation. The VNA ideation method is designed for blue-sky ideation which is more concerned with providing a direction for the ideation. The VNA card includes three types of cards which are Verb, Adjective, and Noun. The VNA card consists of 80 verb cards, 80 nouns cards and 80 adjective cards. Each card is printed with one word. The word library is summarised from an analysis of 40 digital and non-digital games. The following list shows an example combination of card:

- Verbs: buy, blow, guide, switch
- Nouns: note, people, plate, door
- Adjectives: fast, social, silent, high



Figure 2.40:An example set of the words from the VNA (Kultima et al., 2008)

The rule of VNA card is easy to understand. The ideation card design for small group brainstorming. The following step is the brainstorming process. 1) The first player picks a random verb card and used the word to generate a based idea. 2) The second players pick a random noun card and add it to the game idea. 3) The third players pick an adjective card and finalize the game idea. The players repeat the ideation process until the final game generated. At the end of game ideation, the players generated a rough game idea.

In summary, VNA card provides a solution for blue-print game idea ideation. The study shows that the VNA card helps participants to generate new ideas, but the VNA card only available for blue-print game ideation. The player needs more discussion for the final game.

2.2.3.2 PLEX Cards

Lucero and Arrasvuori (2010) designed PLEX Cards based on a framework of playful experiences (Korhonen et al., 2009). The PLEX card is different from VNA card as it is more concerned on the details of game idea. The card consists of 22 cards that focus on playful experiences: challenge, captivation, challenge, competition, completion, control, cruelty, discovery, eroticism, exploration, expression, fantasy, fellowship, humour, nurture, relaxation, sensation, simulation, submission, subversion, suffering, sympathy, and thrill. Each card describes the title and a short explanation of the playful concept. During the design of card, researchers found that the participants may be confused about the card with only one word. Therefore, they provide a short explanation in the cards (see Figure 2.41).



Figure 2.41:The top half shows ‘human emotions’ in an abstract way, with pictures of faces in black and white to focus on the emotion. The bottom half shows concrete examples from ‘everyday life’, with colour pictures of hands suggesting possible interactions (Lucero and Arrasvuori, 2010)

The PLEX card provides two ways to play which are PLEX Brainstorming and PLEX Scenario. The PLEX brainstorming helps to generate ideas in short time. The play rule of PLEX brainstorming is similar to VNA games. The card game requires at least two players. The following step shows the rule of PLEX brainstorming process: 1) Every player picks three cards from dock. 2) The first player add one card as a start point to begin the ideation. 3) The second players add the card and continue the ideation. 4) When the first-round finishes, players write down the idea and continue to polish it. 5) players can repeat the process and get more ideas. PLEX scenario start with a Game Board idea generation game. The players are divided into two groups. This method requires minimum four players to join the brainstorming. The PLEX scenario starts with a gameboard (see Figure 2.42). The following list describes the ideation process of PLEX scenario.1) Each group select three cards from the card and place it to the gameboard. 2) The players develop a scenario by three cards. 3) The story should trigger the first card. It also allows players to adjust the position of three cards. 4) players generated a scenario for the game.

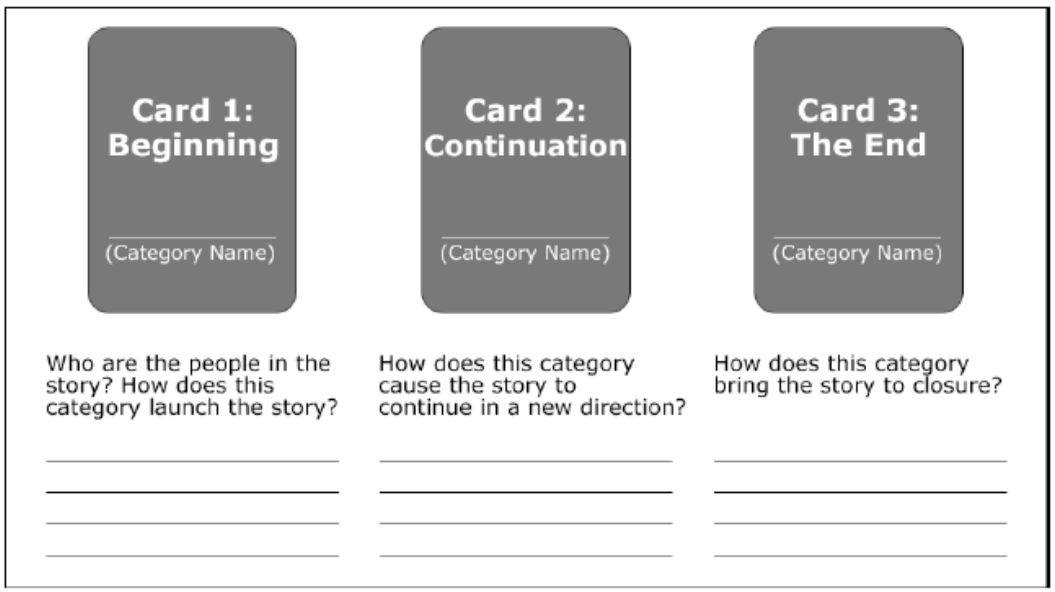


Figure 2.42:The PLEX Scenario template. Questions on the template guide the creation of the scenario. (Lucero and Arrasvuori, 2010)

In summary, PLEX card was inspired by VNA card. The PLEX extends the ideation to playful experience. The PLEX contribute ways for designing for playfulness and the technique helps create huge amount of ideas in a short time.

2.2.3.4 Mixed Reality Card

Wetzel et al. (2017) developed Mixed Reality games for game ideation. The Mixed Reality Game aims to combine interactive digital content with real world environments, objects and actors by different sensors. The Mixed Reality Game Card consists of 93 cards which 51 Opportunities cards are, 18 Questions cards, and 24 Challenges cards (See Figure 2.43). The game aims to support the in-depth idea development of game, such as further expanding and refining and idea. The Mixed Reality Game is different from VNA card and PLEX card. The Mixed Reality Game not only provides playfulness and blueprint ideation but also focuses on in-depth of ideation by encouraging players to identify potential issue in game idea.

The implementation of Mixed Reality Game Cards can be divided into three stages: idea generation, idea development and idea documentation. The game rule of Mixed Reality Game is similar with PLEX brainstorming as follows: 1) Every player picks Opportunity card for brainstorming and generate a base idea 2) Every player picks Question cards and think in-depth of idea 3) Every player picks Challenge cards to polish the final idea.



Figure 2.43:Final iteration of Mixed Reality Game Cards. Examples of Opportunity, Question, Challenge cards, and a blank card (Wetzel et al., 2017)

In summary, the Mixed Reality Game Card provides an ideation card for inexperienced designers combining physical and digital content in game. Comparing with VNA and PLEX cards, Mixed Reality Card is more concerned on the quality of game idea. In addition, the card supports more in-depth development of game idea. Generating serious game idea involving physical environments is a difficult task. One of the design requirements for serious game is to incorporate learning content with game. The Mixed Reality Game Card provides an ideation solution for game design but does not support serious game design.

2.3 Reflection

2.3.1 Definition of Reflection

As highlighted in chapter 2, the role of museums have changed over the years to include the need to support the shaping of cultural identity and community building. Museums can be a place to help shape community identity and bring different community groups together. Through access to objects, information and knowledge visitors can see themselves and their culture reflected in ways that encourage new connections, meaning making and learning (Kelly, 2007). These aspects to include social experiences, reflection and connections between cultures are considered important parts of the experience. As such the goal for visitor engagement needs to be extended to include cultural learning as well as reflection.

Despite an increased interest in designing for reflection, relatively little work actually defines the concept of reflection or provides guidelines on how to design around it (Baumer, 2015). Boud's work on 'reflection in learning' describes reflection as "a generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations" (Boud et al., 1985). Reflection, then, functions as the impetus that moves the individual from examinations of her or his data to action wherein the individual changes his or her behaviour (or perhaps not) based on the resultant increase in understandings (Li et al., 2010). Sengers et al. (2005) further defines the term "reflection" based on critical theory where it refers to bringing unconscious aspects of experience to conscious awareness, thereby making them available for conscious choice. Reflection is not a purely cognitive activity. It gives a new way to people to seeing and experiencing the world

Baumer (2015) summarised two types of reflection from previous studies related to HCI topic. The study points out that reflection can be classified as two types. The first type emphasised on the importance of reflection in the design process. The second type emphasised on the reflection among users, such as encouraging people to reflect their lifestyle based on health data (Nicolini et al., 2014). In another case from Leijen et al. (2009), reflection was used for educational purposes. For example, dancers reflect on recorded video of their performance to improve future performances.

In addition, Moon (2003) give definitions of reflection related to learning. Moon (2003) points out the reflection of learning helps children gain a deeper understanding of knowledge. Barnet and O'Mahony (2006) explains that reflection is the process of obtaining evidence to support our knowledge and beliefs and allows individuals to make conclusions about the future. In the research study of Mann et al. (2007), they classified reflection into two dimensions. The following list shows the two dimensions of reflection:

- An iterative dimension, within which the process of reflection is triggered by experience, which then produces a new understanding, and the potential or intention to act differently in response to future experience. Among the models that conceptualize reflection as an iterative process are Boud, Keogh and Walker (1985) and Schon (1987).

- A vertical dimension, which includes different levels of reflection on experience. Generally, the surface levels are more descriptive and less analytical than the deeper levels of analysis and critical synthesis. The deeper levels appear more difficult to reach and are less frequently demonstrated. The models which focus

on the depth and quality of reflective thinking include Dewey (1933), Hatton and Smith (1995), Mezirow (1991) and Moon (2003).

In conclusion, different definitions of reflection can be found in previous studies. This section reviews definitions of reflection that are related to HCI and education. As mentioned in the previous chapter, the role of museum has changed overtime, initially mainly for educational purposes and now it serves for various purposes such as preserving culture heritages, cultural identity and community building. More engagement is required to support the new role of museums. Since reflection holds the potential to gain a deeper understanding of knowledge, this research proposes a solution to adopt reflection as a new engagement to support museum exhibition. It aims to encourage visitors to reflect on the cultural content rather than reading descriptions of artefacts.

2.3.2 Concepts

The reflection activity helps people to get a better understanding of the world. It provides a chance to interpret what is going on around us and the implications of our actions (Sengers et al., 2005). This section focuses on the concepts to designing for reflection.

The current study of reflection related to education can be classified into reflective teaching and student reflection. Reflective teaching mainly focuses on reflecting teaching process. For instance, Zeichner (1987) points out that the reflective teaching is one of the ways to enhance the quality of teaching. There is evidence that reflective discussion helps to improve teaching quality. In addition, reflective discussion helps in figuring out the issues that was frequently neglected in teaching. Andrew and Teitelbaum (1983) gives a comparison study on reflective teaching where the result shows that reflective teaching provided better learning effect than traditional teaching.

Additionally, the reflection on learning is another type of reflection in the field of education.There are lots of research can be found to increase student learning effect by reflection (Yang, 2009; Conderman, 2011). For instance, the research by Ash et al. (2005) integrated reflection and assessment to capture and improve student learning. The study uses self-learning guide book which contain learning material and discussions for students to learn about nutrition. The result of evaluation shows that reflection helps the teacher to understand how the students think and how to support the student to think more deeply. Some researchers have previously tried to adopt reflective learning in museum. For example, the study from Gaufberg and Williams (2011) uses a gallery visit and art images as reflective trigger. The tour requires visitors to explore museum with a

set of question cards. The question cards help visitors to build a connection between a work of art and some aspect of life or medical practice. At the end of the tour, visitors share the reflective result with peers. The evaluation result suggests that reflection practice shows its effectiveness at encouraging meaning discussions and community building.

The design for reflection is not limited to education. Reflection is described as providing increased self-knowledge for people in previous studies (Branham et al., 2012; Gao, 2012; Zhao and Cosley, 2012; Wallace, 2013). Self-knowledge is defined as encouraging positive behaviours of people based on personal informatics. People have incomplete knowledge of themselves where they cannot monitor their behaviours all the time, and they cannot easily find patterns in their behaviours. Therefore, self-knowledge and self-reflection help to increase self-control, and promote positive behaviours. Li et al. (2010) proposed a concept of a personal informatics system that helps people collect personal information for self-reflection and the gaining of self-knowledge. The personal informatic system includes five steps which are motivation, collect data, integrate, reflect and action. The study points out that reflection plays an important role in personal informatic system. Reflection helps people to reflect the data and change their behaviours. Another research from Bampatzia et al. (2016) conducted a study to stimulate history reflection in cultural heritage through social media. The research involves a personalised tour application to encourage the visitors to reflect on culture contents.

In addition, persuasive technology encourages reflection activity to change attitudes and behaviours. Comparing with reflection of personal informatics, persuading to reflect has a specific goal to be achieved, such as to persuade people to be aware of their health status based on their health data (Orji and Moffatt, 2018). Comber and Thieme (2013) designed a recycling system to improve recycling and food waste through persuasion, social influence and aversive effect. The system encourages participants to reflect on wasted food in recycle bins every day. The result of evaluation shows the system is able to increase environmental awareness of participants.

To summarise, this section reviewed three concepts related to reflection. Reflection is widely implemented in the aspect of education as it provides a deeper understanding on educational contents. The concept of self-knowledge encourages people to explore the relationship between themselves and the world. Persuasive reflection proposes an approach to increase awareness of people and even change their attitudes and behaviour through reflection. While some researchers have applied reflective learning in

museum, designing for reflection is still limited to the various fields, such as education, health care etc. This research aims to explore new approaches to incorporate reflection with technology in museums.

2.3.3 Technology to Support Reflection

There has been an increasing interest among the HCI community to design for reflection using emerging technology. The study by Sengers et al. (2005) has summarised several approaches to HCI to support reflection design. The study argued that reflection on unconscious values embedded in computing should be a core principle of technology design. The following list shows several approaches to embed unconscious values in system design:

- **Participatory Design**: Participatory design (PD) is one of the ways to involve users in system design (Muller, 1994; Kyng,1991; Bodker, 1991). PD advocates changing not just systems, but also getting suggestions from users during system design. In short, Participatory design develop system based on the reflection of users.
- **Value-Sensitive Design**: value-sensitive design method (VSD) was proposed by Friedman et al. (2013). value-sensitive design method develops a system based on the identified stakeholders, fundamental values, and trade-offs among values pertinent to the design. In short, the reflection design based on the value of information from system users. The system should focus on the user group and provides valuable content for reflection.
- **Critical Design**: Critical design was proposed by Tales (1999) and Dunne (2001). The goal of critical design provides a different view of point to users. A critical designer design object not to do what users want and value, it should introduce both designers and users to new ways of looking at the world. it means the technology should support users have a new view of point to looking at the things.
- **Ludic Design**: ludic design was proposed by Gaver et al. (2004) ludic design focus on reflection and engagement through the experience of using the designed object. In the context of HCI, ludic design explores the limits of technology design practice. The ludic design different from critical design, it more prefers to trigger reflection on experience.
- **Critical Technical Practice**: Critical technical practice (CTP) was highlighted by Agre in his 1997 book Computation and Human Experience. This approach is different from previous mentioned approaches. It is based on Artificial

Intelligence view. CTP synthesizes critical reflection with technology production as a way of highlighting and altering unconsciously-held assumptions that are hindering progress in a technical field. The Critical technical practice aims to understand human behaviours from technical aspect.

- **Reflection-in-Action**: Reflection-in-Action is a concept proposed by Donald Schön (1983) and echoed in recent HCI work on embodied interaction. They proposed reflection as an active, in the moment, and almost intuitive, visceral process as opposed to a detached cerebral analysis occurring pre- or post-engagement. In other words, reflection-in-action aims to trigger reflection by an element of surprise were moving from unexpected design.

The following six principles have been proposed by Sengers et al. (2005) to help designers to design for reflection activity with technology. 1) Designers should use reflection to uncover and alter the limitations of design practice.2) Designers should use reflection to re-understand their own role in the technology design process.3) Designers should support users in reflecting on their lives.4) Technology should support scepticism about and reinterpretation of its own working.5) Dialogic engagement between designers and users through technology can enhance reflection.6) Reflection is not a separate activity from action but is folded into it as an integral part of experience.

In addition, Fleck and Fitzpatrick (2010) have identified a reflection framework consisting of five levels of reflection as shown in figure 2.44:

- R0 Description: Revisiting description or statement about events without further elaboration or explanation. Not reflective.
- R1 Reflective Description: Revisiting with explanation description including justification or reasons for action or interpretation, but in a report or descriptive way. No alternate explanations explored, limited analysis and no change of perspective.
- R2 Dialogic Reflection: Exploring relationships; a different level of thinking about. Looking for relationships between pieces of experience or knowledge, evidence of cycles of interpreting and questioning, consideration of different explanations, hypothesis and other points of view.
- R3 Transformative Reflection: Fundamental change; revisiting an event or knowledge with intent to re-organise and/or do something differently. Asking of

fundamental questions and challenging personal assumptions leading to a change in practice or understanding.

- R4 Critical Reflection: Wider Implications where social and ethical issues are taken into consideration. Generally considering the (much wider) picture.

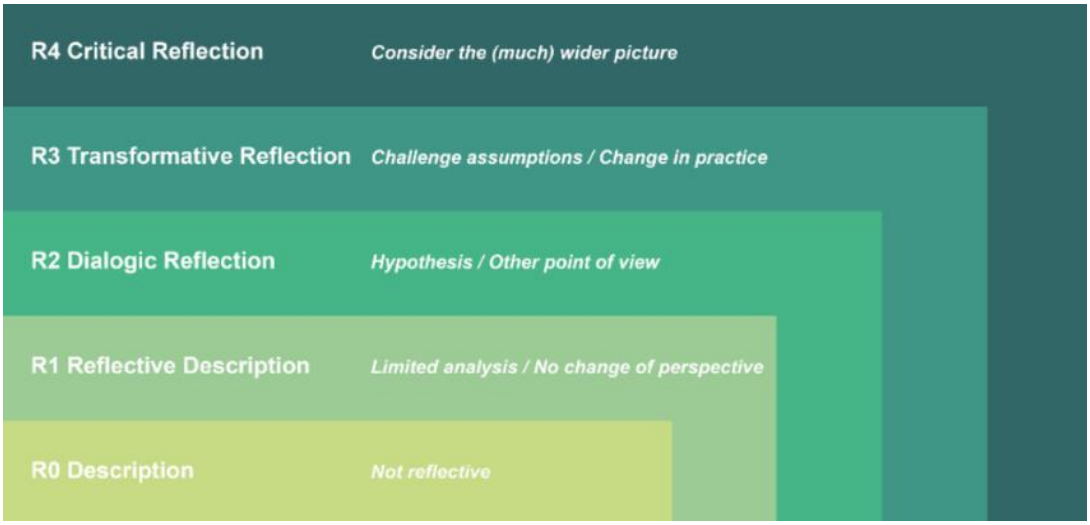


Figure 2.44: Reflection Process (Fleck and Fitzpatrick,2010)

Currently, most research projects are explored values of museums from communication, social experience aspects. The cultural reflection aspect is lacking. A lot of research projects have mentioned reflection in museums, but the effect of reflection is not obvious for visitors. Therefore, the thesis project aims to create a new narrative way to encourage user engagement and reflections through novel technologies. The following sub-sections review existing technological solutions for supporting various types of reflection.

2.3.3.1 Mobile App for Learner Reflection

Leinonen et al. (2016) implemented a design-based research approach to explore how applications designed for mobile devices could support reflection in learning in K-12 education. Due to the previous education applications are scarce for collective learning. Therefore, the research presents two mobile education applications to support collaborative learning through reflection.

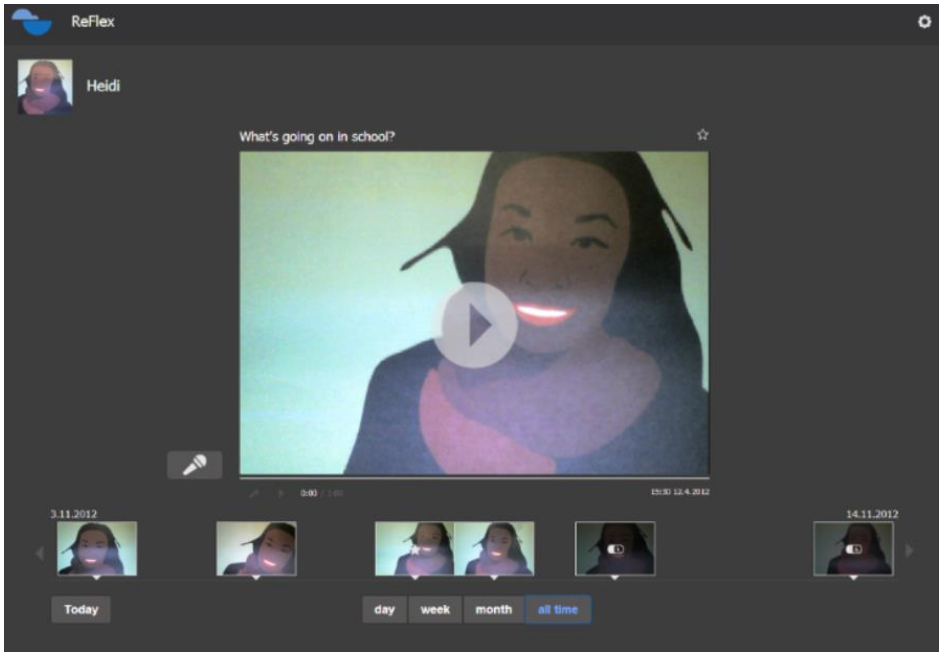


Figure 2.45: Illustration of the ReFlex interface (Leinonen et al., 2016)

The design of the mobile application is based on insights gained from Fleck and Fitzpatrick's (2010) framework of levels of reflection. Two mobile application was developed by researchers which is ReFlex and TeamUp. ReFlex is a video clip mobile application for individual reflection. Learner to record 60-second audio-visual clips of their personal learning experiences, store the clips on a timeline and share them with teachers, peers and parents. As shown in figure 2.45, ReFlex triggers reflection by a simple question, such as "What's going on in school?". The question guides students to reflect on their learning experience and the relationship between learning and school. Moreover, teachers can plan individual guidance and consultation based on student reflection record. TeamUp is a reflection tool designed to support student group project. The mobile application encourages students to reflect upon their team project. As shown in figure 2.46, the students record video clip for reflection purposes. The reflection based on several questions, such as "(1) What we did (2) What we will do and (3) Any problems?". The videos enable students to reflect in-depth about their own work. In addition, it allows the student to understand other group members activity and thinking. In the teacher view, the mobile application provides a valuable way for them to understand the progress of the student group project. The two mobile applications were evaluated by 7 schools. The result of evaluation shows that the apps can help students to perform reflection, but to trigger higher reflections will require more guide by teachers.

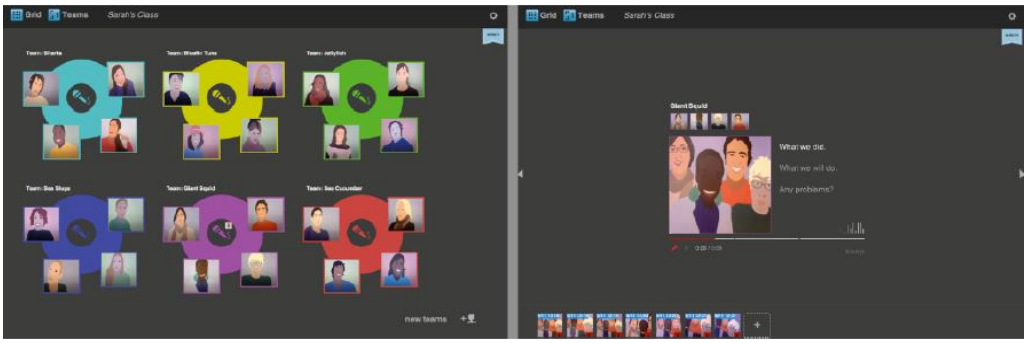


Figure 2.46:Illustration of the TeamUp interface (Leinonen et al., 2016)

2.3.3.2 Design IoT System to Support Reflection

Ghajargar et al. (2018) have proposed a relational approach to designing IoT systems that support reflective thinking. In the HCI field, reflection refers to the action of thinking about the data provided by computing artefacts (Baumer et al., 2014; Sas and Dix, 2011). The research focuses on supporting "make me think" relationship in IoT system.



Figure 2. 447:Two different types of light behaviours: A) to arise mode and B) to accumulate mode (Ghajargar et al., 2018).

The research introduces a lamp prototype consisting of several components (see Figure 2.47). A mobile app senses and collects data related to user activity, such as cycling and walking. The lamp behaviours are related to user's urban mobility behaviours. The study aims to encourage users to reflect on the relationship between urban mobility behaviours and the quantity of CO2 emissions. For instance, if the user keeps driving car, the light will arise to help users realise that their urban mobility way produces CO2 emissions.

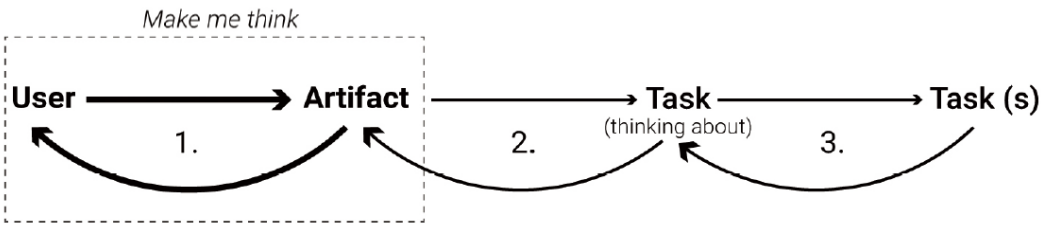


Figure 2.48:“Make me think” Model

Overall, the research contributed a “Make me think” model to emphasis reflection to IoT system (see Figure 2.48). In the end of research, it summarises the four fundamental components of an IoT system which are user, computer artefact, user activity and situation. There are several reflection suggestions based on the model: 1) The balanced relationship and collaboration between user and artefact. 2) The artefact should be related to another activity that needs reflection. 3) The user needs to understand the relationship. In the end, the artefact should encourage the user to think more than finish task. In short, the study suggests triggering reflective thinking by exploring the relationship between user activity and artefact task.

2.3.3.3 The Role of Reflection for the Player Experience

There are many researchers who develop game to enhance immersion and enjoyment for players. The play experience is also one of the ways to support reflection. Authors Maesh and Costello (2013) proposes not only positive engagement and provoking experiences, but also encourage players to have more reflection. Authors Iacovides and Cox (2015) propose a persuasive game that may help people reflect on blame culture in healthcare. Another research by Bopp el al. (2016) requests players to describe their feelings after the gameplay. These studies show how reflection can be supported by player experience.

Mekler et al. (2018) presents a study to explore the role of reflection for player experience in more detail. The study implements semi-structured interviews as a method to investigate the evidence of player experience in reflection. The interview involves participants from different locations with different level game experience. During the interview, the interview questions are based on the theory of Fleck and Fitzpatrick (2010)’s framework such as (1) Outside of actually playing a game, are there times when a particular game or gameplay experience has been on your mind? (2) Do you ever intentionally reflect on your gaming experiences? (3) Did you ever have any thought-provoking experiences as a result of playing games? The result of evaluation shows that low level reflection is common in the game experience, but the high level reflection

(transformative reflection and critical reflection) is absent. In addition, the study highlights the difficulty in evaluating reflections and contributes an example of applying the levels of reflection framework to evaluate the player reflective experiences.

2.3.3.4 Physical Interaction to Support Reflection

Engaging users in physical activity is one of the ways to support reflection (Moher et al., 2014; Ghajargar et al., 2018). Recently, with the widespread use of wearable device and smartphone, data-driven reflection becomes a trend in ubicomp technologies and IoT technologies (Landi et al., 2016; Standal and Rugseth, 2016; Al Ardha, 2018). This section discusses several case studies on using physical activity to support reflection.

Consolvo et al. (2009) introduces a persuasive system to analyse data from wearable device to trigger self-reflection for users. Persuasive technology is a kind of technology that encourages people to have better behaviours in life. A recent trend in computing is to develop persuasive technologies to help people change their behaviours to support the lifestyle (Matthews et al., 2016; Oyibo, 2016; Halttu and Kukkonen, 2017; Ghajargar, 2018). However, Miyamoto et al. (2016) argued that tracking health data may result in the awareness and reflection of user daily activity, but it may not be enough to support long term reflection.

In conclusion, most research is concerned about support self-reflection through physical activity data. The previous study showed health data helps reflection and change behaviours in the short term. Since the data-driven reflection have low reuse rates, researchers have suggested to explore a way to increase reuse rates, such as by using playful technology (Tikka et al., 2019).

2.4 Conclusions

This chapter reviewed literatures from three aspects:1) digitalization of museum, 2) Existing Toolkit, 3) Reflection. Digitalization of museum briefly summarises the state of the art in digital museum. Existing toolkit summarizes the advance technologies can help museum explore more engagement and provide better experience. In the end, it reviews the concept of reflection and review previous research to enhance learning experience in health care and education aspects.

Over the years, the role of museum has changed from showing collection to preserving cultural heritage, support cultural identity and community building. Previous research points out that museums play an important role to help people understand cultures from

different countries. For example, the case study in West Africa shows evidence that the national museum can promote a sense of nationalism and national unity. In addition, the museum has been important in supporting social community building. The museum has become a place to provide courses and exhibition for those people who have similar interests to share and exchange knowledge.

Nowadays, technology has been applied to increase visitor engagement in museums. Historically, the mobile technology has been implemented as a tour guide for museum visitors. In recent years, VR and AR provides immersive museum experience by presenting stories in VR environment. In other aspect, TUI provides physical interactions between visitors and the interact exhibit. During the physical interaction, it encourages visitors to share and focus on the artefacts and physical environment. IoT technology provides new interaction capabilities for augmented objects or smart objects to enable interactive user experiences.

In addition, Software and hardware toolkits are essential for developers as well as non-experts to create IoT products and solutions easily and productively. Examples of IoT software toolkits include RapIoT and IoTLink for use in IoT system development within industry settings. Similarly, game engine such as Unity3D allows developers to develop games easily. However, conventionally Unity3D does not support communication with external IoT devices such as sensors and actuators, making IoT serious game hard to develop. Hardware development board such as Raspberry Pi and Arduino provides the computing platform to create embedded IoT solutions, with Raspberry Pi having higher computing performance than Arduino. As such Raspberry Pi was chosen as the hardware development platform for the thesis work. Recent studies on card-based ideation tools have shown that they are indeed effective for brainstorming A few card-based ideation tools have specifically targeted game idea generation such as VNA, PLEX and Mixed Reality Card Game. The thesis work as described in chapter 7 further describes a proposed a card-game solution synthesising design knowledge of IoT serious game design in museum

The definition of the term ‘reflection’ was presented and discussed in detail to include related concepts and design principles. The chapter also examines several technological approaches with example case studies as to how design for reflection has been emphasised and evaluated. For example, the approaches to incorporate physical interaction and gamification elements have been explored as ways to support reflection in education and healthcare. Some studies reveal the difficulty in supporting higher level of reflections where no such evidence is observed in a particular game study focusing

on reflection in player experience (Mekler et al., 2018). The method of evaluating reflection is a difficult process. Fortunately, Fleck and Fitzpatrick (2010) provides a reflection framework as basis for studies to apply in evaluating reflection. In addition, there is limited research on the integration of reflection in museum tour. As such the thesis project focuses on designing for reflection in addition to learning as a new engagement for museum experience.

In conclusion, there are many human computer interaction studies focusing on exploring new role of technology in museums. Currently, most HCI studies implemented mobile technology and tangible user interface to enhance the museum experience for museum visitors. Current studies of digital museum are still limited to design strategies such as designing for immersion, interactivity and gamification. In order to meet the changing role of museums, museums require more new ways to engage visitors in achieving higher level of reflection. Therefore, the thesis explored ways to enhance visitor engagement in cultural learning and reflection by exploring IoT and gamification approach to support physical interaction and multisensory experience. At the end, it contributed towards the development of an IoT toolkit to help future museum innovation.

Chapter 3. Pilot Project

3.1 Project Goal and Objectives

This research starts with a pilot project that cooperated with Baba Nyonya Culture Heritages Museum. The research aims to enhance museum value through technology approaches. In the early stage of pilot project, the research team have an investigating meeting with museum curators. During the meeting, the research project identified the valuable content and gathered requirements from the museum. The project goal and objectives were generated from the initial data gathering meetings. The research project identified the following objectives for pilot project:

1. To design and develop interactive exhibits using IoT technologies to support physical, hands-on learning to allow users to interact with physical and/or virtual replicas of historical artefacts.
2. To evaluate the effectiveness of interactive exhibits in supporting cultural learning.
3. To investigate impact of physical interaction and multisensory experiences in supporting more engagements among visitors.

3.2 Project Context

This project is carried out as part of research collaboration with Baba Nyonya Heritage Museum, Malacca. The Baba & Nyonya Heritage Museum is located in Malacca, a World UNESCO Site. The house is a combination of three terrace lots that were acquired by the Chan family in 1861. Four generations lived in the house before it was opened as a museum in March 1985to preserve the Chan ancestral home for future generations. This project aims to promote a sense of social and common identity, with the goal of building a society embodying tolerance and unity in diversity. This is in line with the museum's vision of bridging communities to Malaysia's history through Peranakan culture. Peranakans, also known as the Babas and Nyonyas mean children of the land where the Babas were the males and Nyonyas the females. Peranakan people were usually local-born child with a foreign parent whom most likely is at the Straits of Malacca for trading (Lee, 2008). The main objective of this project is to incorporate serious games to facilitate inter-racial and inter-generational learning and dialogues linking past and present. More new technological solutions for promoting cross-cultural reflections will be needed as increasing number of countries in the world go through a time of racial

polarisation, resulting in little empathy for each other's community, and thereby creating mistrust between the different ethnic groups in the nation.

3.3 Requirement Gathering

Since this is a research project in collaboration with Baba Nyonya Heritage Museum, Malacca, the following requirement gathering activities were carried out:

- Participating in the personal guide museum tour and multiple site visits
- User ethnography study
- Interview with museum curator and staff

Baba-Nyonya is a unique community, rich with the traditional heritage, cuisines, fashion and arts. The evolution of this unique ethnic group dates as far back as 500 to 600 years when Chinese traders arrived in the Malay Peninsula, the nucleus of which was Malacca, the centre of the Malacca Sultanate. These traders then intermarried with the local women due to their long stay at the Malay Peninsula. When the community gets larger over certain period, they married exclusively amongst their own. The term of Peranakan (also known as Baba-Nyonya) commonly refers to the descendants of immigrants and Malay. Peranakan Chinese group is one of the biggest communities in Malacca. The culture of Peranakan Chinese is a mix of two dominant cultures Malay and Chinese – with some elements from Javanese, Batak, Siamese and European (specifically English) cultures (Lee,2008). Besides the Peranakan Chinese, there were also many other Peranakan communities in Malacca, such as Peranakan Indian (Malacca Chitty), Portuguese-Eurasian and Indo-Malays. Today, the Babas and Nyonyas embody the idea of cultural diversity in unity.

The Baba Nyonya Heritage Museum tells the story of a Peranakan Chinese family. The three terrace houses that make up the museum were acquired by the Chan family in 1861(See figure 3.1). Since 1861, four generations of the Chan family have lived in the home. It was opened by the family to the public in 1985 with the mission of preserving the Chan ancestral home for future generations. Other museum roles include to document and exhibit the history of Peranakans in Malacca and their role in the development of Malaysia and to provide a better understanding of the shared history and culture between races in order to achieve greater unity among Malaysians of different ethnic background.



Figure 3.1:Baba & Nyonya Heritage Museum

At present, the museum provides self-guided tour and hourly personal guided tours. In self-guided tours, visitors can explore the museum using the book tour. In the personal guided tour, groups of visitors (ranging from 2 to 40 people per group) will take about 30 minutes to complete the tour. Family groups with young children were identified as target groups in this project as they were the least engaged in the existing tours. Through brainstorming sessions held with the museum curator, the project team identifies the cultural learning theme on food and jewellery as possible topics that may interest the target users(See figure 3.2).

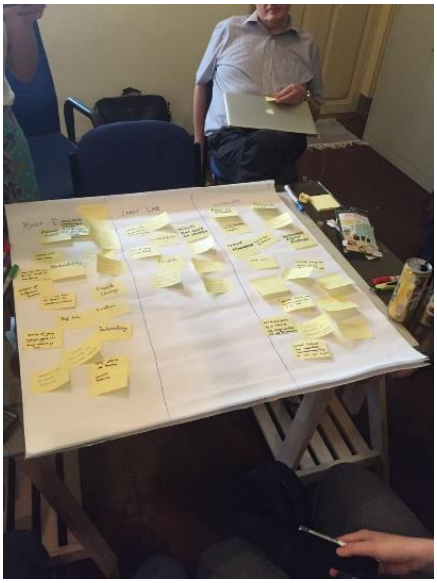


Figure 3.2:Brainstorm meeting with museum curator

3.4 Design Consideration

In the first phase of the research project, various interactive exhibit ideas were brainstormed and explored. The design of two interactive exhibits were finalised,

developed and evaluated in a series of public trials. The aim of the interactive exhibits is to highlight the rich diversity in the Peranakan culture (east and west influences, and different Peranakan ethnicities itself) through learning by making. The proposed exhibits allow users to simulate the process of '*kuih'* (or cakes) making using a historical artefact called 'Batu Boh' (or known as grinder) and to make a Peranakan jewellery. The different cultural influences were portrayed in the choice of '*kuih*' and jewellery brooch that a user may choose to make (e.g. in many culturally-influenced styles such as Indo-Malay, Chitty, etc.). One of the most important design goals is to create an immersive, multi-sensory experience for users to include sense of touch, smell, audio and visual. The prototype exhibits will be further described in Chapter 5.5. The following section describes the technical requirement for their developments.

The Goldsmith jewellery making exhibit station is a motion-based simulator developed using Unity3D, Arduino and Leap motion as the motion detection tool for user interaction to interact with virtual objects on a screen.

Unity is a combination of project editor, run-time player and game engine for 3D game development, consisting of two components which are Scenes and Game Objects. Scenes is used to construct a virtual world for games. Game Object plays an important role in the development of Unity3D. As the graphic shows in figure 3.3, it is impossible to create a unity game without game objects. Every Game Object contains a set of components. Typically, Game Object uses to bridge 3D models and programming script. The programming script uses to control variables in the components of game objects, such as mass and positions of objects. In addition, Unity supports the components developed by other companies through plugin SDK from other companies. It provides a chance to integrate different hardware and function to Unity.

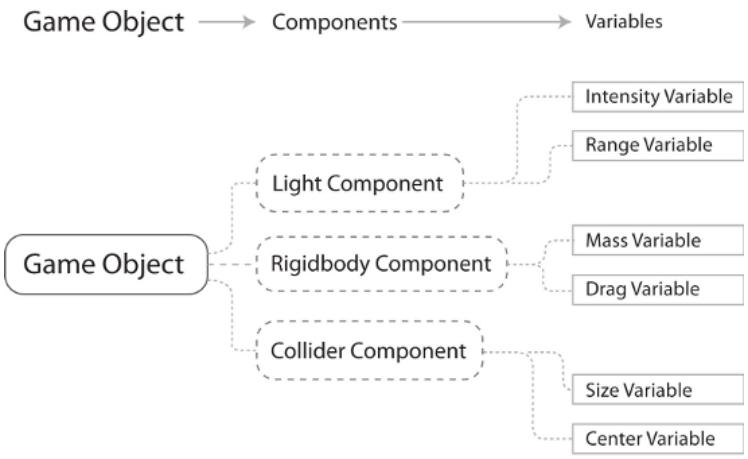


Figure 3.3:Unity structure

In the hardware development of the Goldsmith simulator, it uses a motion detector and Arduino. There are two types of commercial motion detectors available for developers. The first is for body detection, such as Kinect and Intel sense. The other one is small scale motion detectors, such as Leap Motion and IR sensors. In order to develop the Goldsmith simulator, the technical requirement is a motion detector that can control the virtual environment through hands. Leap Motion is a controller that enables the tracking of hands. Leap Motion provides tracking data for Unity developers through Leap Motion SDK. Arduino is a single board computers with GPIO pins for sensors. The sensors can communicate with Unity through Arduino.

The Batu Boh simulator is developed using IoT technologies. The project creates a replica of Batu Boh and embeds it with sensors and actuators. The physical simulator consists of Raspberry pi, sensor networks and motors. Raspberry pi is the core of physical simulator. It was a type of single board computer. This device can provide maximum 24 GPIO pins for sensors and motors. The computer is used to process sensors data and communicate with servers. In addition, the sensors network and motors were programmed in Python and using Pygame library.

3.5 Development

3.5.1 Goldsmith Simulator

Early Malacca was a melting pot of different cultural influences. Therefore, the style of Peranakan jewellery is influenced by different cultures. In the past, goldsmiths would be commissioned to work in homes to make unique and intricately designed jewellery pieces, such as krosang, brooch, bracelets and even tiaras. These goldsmiths were skilled in setting the finest jewels and would work with the Nyonya to design something she had seen or could imagine. Today, goldsmiths work in shops and no longer easily found. The art of jewellery making is a fast disappearing trade.

The design of the pilot project is as such that users will be able to experience the old trade of jewellery making through mixed reality technologies. The goldsmith simulator is developed using a motion detector and virtual technology. Figure 3.4 shows one of the Peranakan Jewelleries. In the past, a Nyonya would provide a table for the goldsmith to make a commissioned jewellery in her own home. To make a coin pendant, the Nyonya would choose a frame (which also depended on her Peranakan ethnicities) and a British coin (where English Sterling and US Dollar were often used as parts of Nyonya jewellery).

The goldsmiths would then calculate the price using a daching (a traditional weighing tool) and use a hot solder with air pump to solder the frame and coin together. The goldsmith simulator allows users to put themselves in the shoes of the goldsmith to experience the process of jewellery making. At the same time, the simulation system encourages users to explore different Peranakan culture by introducing different types of Peranakan Jewellery.

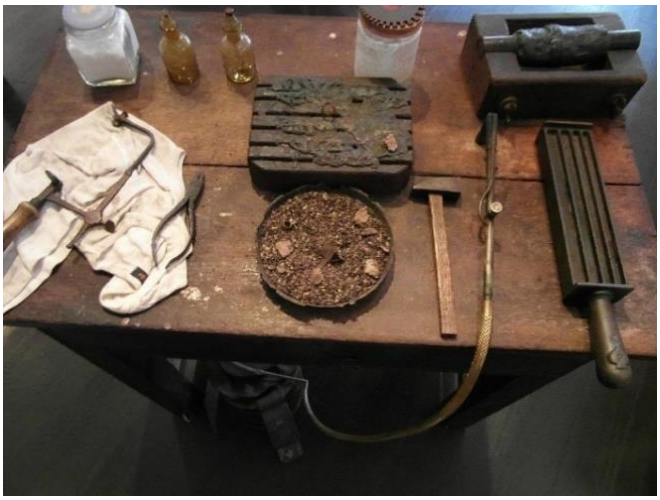


Figure 3.4:Goldsmiths workstation

The goldsmith simulator allows users to undertake the making process of a Peranakan pendant in four steps: 1) As the Peranakan pendant consists of a frame and coin, the user will need to choose one frame and one coin. 2) the user will then pick up a daching to calculate the price of jewellery depending on the weight of the frame and coin. 3) the user will pick up a torch soldering gun and step on a physical bellow to pump air in order to start the virtual soldier fire, 4) at last, the user will virtually solder the frame and coin together. Figure 3.5 shows Peranakan Pendant. The simulator mixes physical and virtual user interactions to create an immersive experience for users.

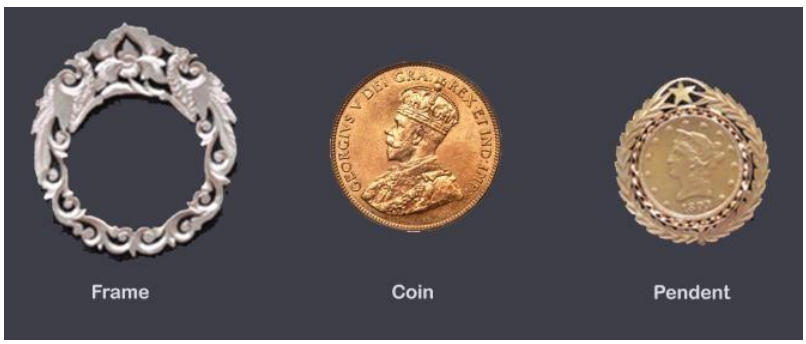


Figure 3.5: Peranakan Pendant

3.5.1.1 System Analysis and Design

This section will explain the detail of system analysis and the design of Goldsmith station. System analysis will identify the requirement, functional and non-functional requirement. The system requirement is generated from current research and museum tour. System design will describe the design of goldsmith simulator, such as the user interface design. The following section will describe system requirements, user case diagram, activity diagram, system architecture, and user interface design.

3.5.1.1.1 System Requirement

The system requirement can divide into hardware and software requirements, and functional requirement. The hardware and software requirement will list the minimum requirement of the system. The functional requirement will explain specific task of the system.

The following list is the minimum hardware and software requirement for goldsmith simulator:

- Windows 7 or above
- Leap Motion SDK
- Leap Motion Controller
- AMD Phenom II or Intel Core i3 processor
- Camera
- 2 GB RAM
- USB 2.0 port
- Internet connection
- Arduino Uno3
- IR sensor

The following list is the requirement of development tools:

- Unity3D
- Leap Motion SDK
- Arduino SDK

Table 3.1 shows the functional requirement of Goldsmith simulation system. The functional requirement is based on feedback from the museum curator.

Table 3.1:Functional requirement

No	Description
FR1	The game needs a tutorial video to describe goldsmith and Peranakan Jewellery.
FR2	The tutorial video can be skipped.
FR3	The motion detector should be easy to interact with 3D model.
FR4	The virtual 3D environment should be similar to a goldsmith work table.
FR5	The system should have an audio instruction for users.
FR6	The 3D model will be part of instruction.
FR7	IR sensor should be integrated with a physical bellow from museum.
FR8	The user can select finish or get a digital souvenir when finish the simulation.
FR9	The digital souvenir can be uploaded and downloaded through QR code.
FR10	User can reply the game.

3.5.1.1.2 Use Case Diagram

User case diagrams are used to represent the interaction between user and system. There are two actors in the project which are user and server. The following Use Case Diagram demonstrates the relationship between different function and user. Table 3.2 describes the detail between actor and User case.

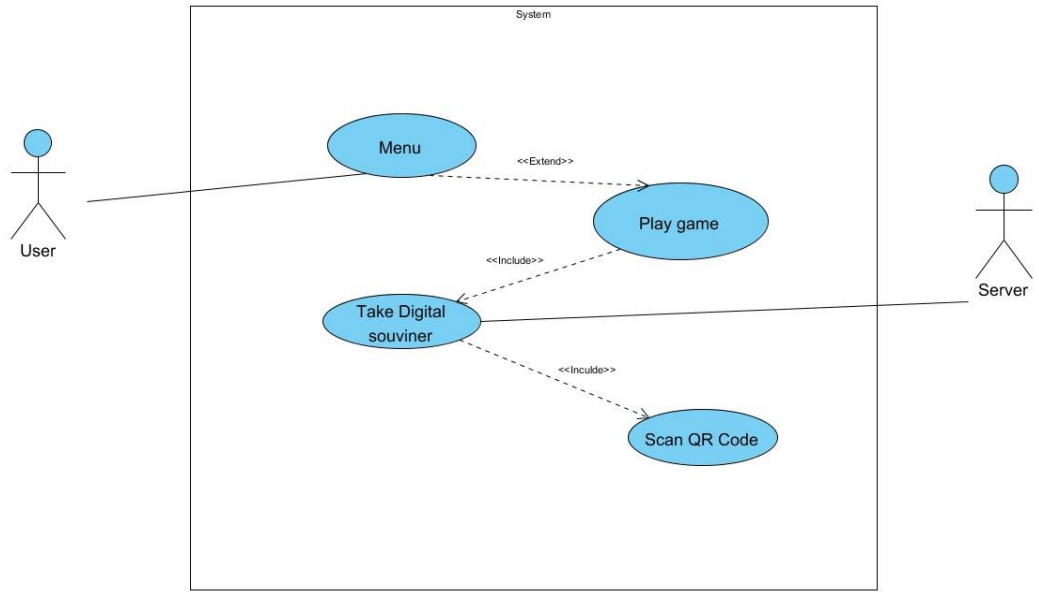


Figure 3.6:User Case Diagram

Table 3.2:User Case Description

No	User Case	Actor	Relationship	Description
UC1	Menu	User	Association && Extend UC 2	The use case allows user play video game.
UC2	Play Game	User	Association && Include UC3	The main game of project. User can simulate the process of making Jewellery.
UC3	Take Digital Souvenir	User && Server	Association && Include UC4	When game finish. User can take a photo as digital souvenir. System will upload photo to server and generate a QR code.
UC4	Scan QR code	User	Association	User can get a special photo as digital souvenir through scan QR code.

3.5.1.1.3 Activity Diagram

Activity diagram shows the dynamic behaviours of the system. It presents the flow from first activity to the last one. Activity Diagram is listed down workflow of the whole project. Figure 3.7 shows the workflow of goldsmith simulator. The following section will explain each activity of activity diagram.

The first activity of diagram is **Menu**, it presents the first page of goldsmith simulator. When user select start the system, it will be automatic **Play Video**. In Play video, user can skip the tutorial video.

When the tutorial video is done, it will automatically navigate to the main game. The main game includes four activities: **Pick Up coins and frames**, **Balance Weight**, **Pick up Torch gun** and **Soldering Frame and Coin**. Moreover, the activities are used to simulate the process of making a Peranakan Pendant. One activity must be finished before moving to next activity.

The user can take a special photo as a digital souvenir when they finish the simulation. If the user selects Digital Souvenir, it will navigate user to the take photo page and users can take a photo as a digital souvenir. In the end, the user can download the photo through a QR code.

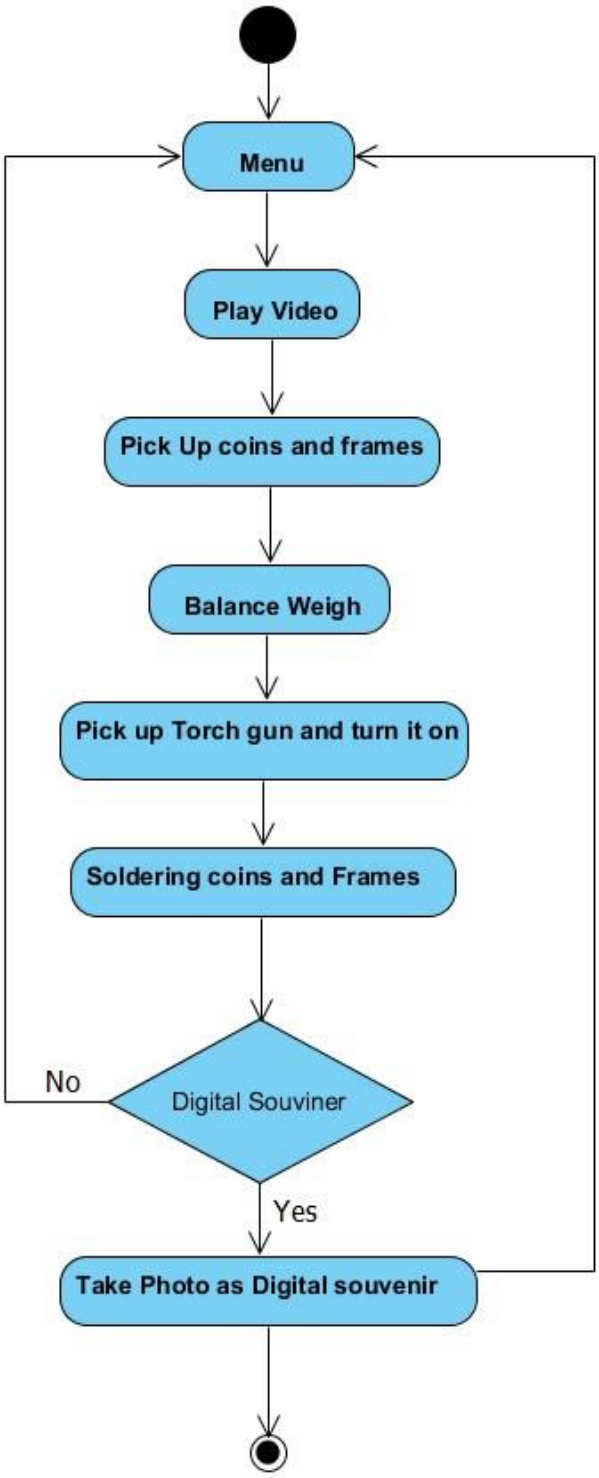


Figure 3.7:Activity Diagram

3.5.1.1.4 System Architecture

This section will explain the architecture of goldsmith simulator. The goldsmith simulator consists of three components which are Menu, Main game, and Digital Souvenir. The following part will explain the functions of different components.

The system is based on motion detector technology. In the page of Menu, users need to active “Play” button through Motion detector. When user select play button, it will play a video with educational content. The user can select "Skip" button to enter next page, the function of skip button is design for the replay user. It will navigate to Main Game page when the video is done.

Main Game is the main function of goldsmith simulator. The main page of the system consists of a 3D virtual environment. The interaction between users and the virtual environment is based on Leap Motion, a motion detector. There are four steps in the main game. In first step of the simulator, the user needs to pick up one coin and one frame. The camera will automatically move when they pick up one frame and one coin. In the second step, user needs to pick up daching and balance the weight. In the third step, the user needs to pick up torch gun and pump the physical bellows to turn on the torch gun. At last, User needs to use torch gun to soldering frame and coin together. When the pendant is done, the user can choose to collect digital souvenir or back to the main page.

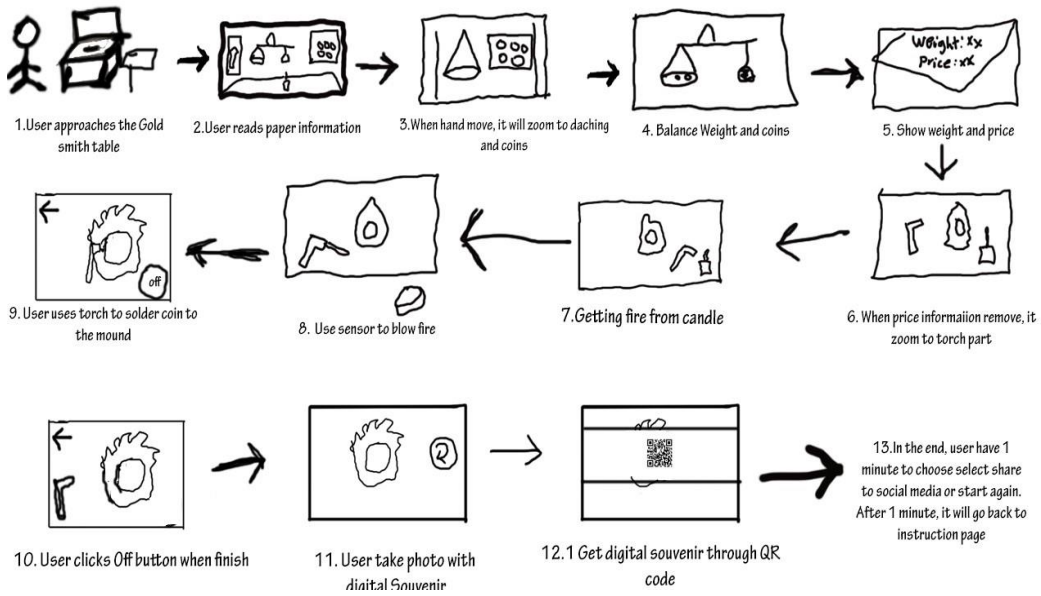


Figure 3.8: The process of goldsmith simulator

Digital Souvenir is a page that provides a chance for users to take a photo with a virtual pendant. When users click take photo button through motion detector, they have five seconds to adjust their body position. When the photo is taken, it will upload the photo to the server and generate a QR code. Users can get digital souvenir by scanning the QR code. All photos will be automatically deleted after 10 hours.

3.5.1.1.5 User Interface Design

This section will discuss the user interface design of the system. In the design of user interface, it aims to create a similar virtual environment to a real goldsmith work table. Figure 3.9 has a Peranakan house as the background. User uses motion detector to touch the Play button. In addition, there is a skip button.



Figure 3.9: User Interface Design of Menu

In the main game, the interface is a virtual environment. In the virtual environment, there is a goldsmith work table and Play to start simulation. The display is controlled by a component call camera in Unity3D. The User interface of the system is controlled by programming code and camera of Unity3d. Figure 3.10 shows the virtual environment design and some game scenes.

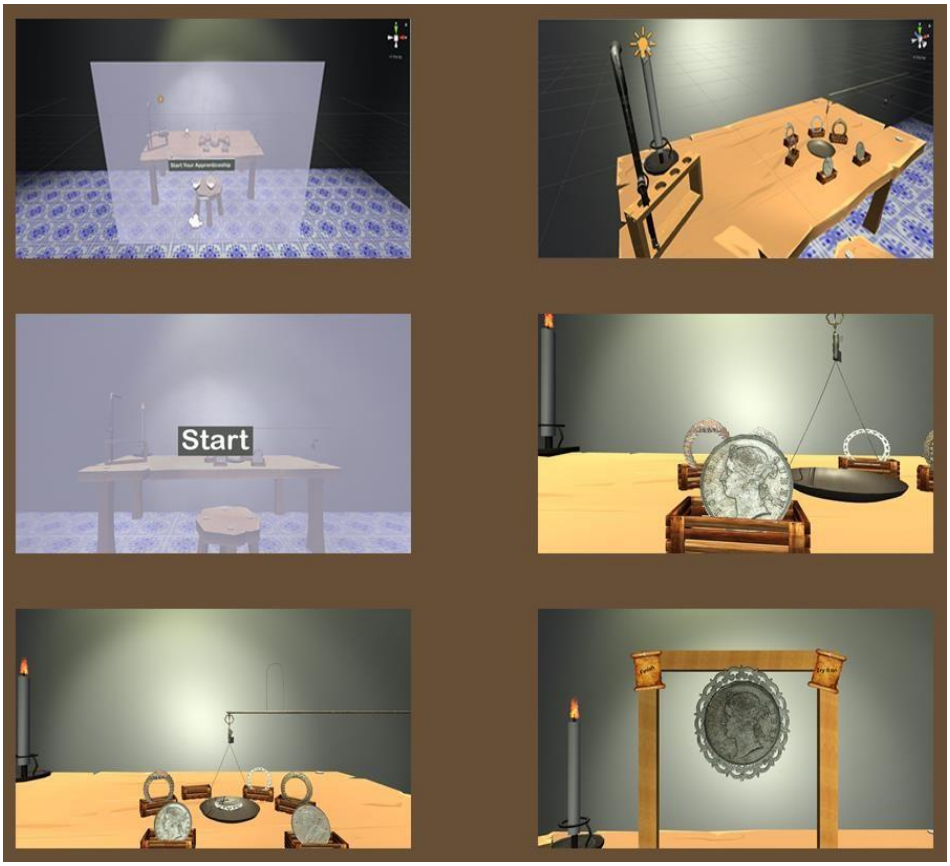


Figure 3.10: Main game environment

In the design of Digital souvenir page, it uses an old fashion switch as button. There are four buttons which are **take photo**, **delete**, **confirm** and **next**. When user selects to take photo, it has five seconds for users to adjust his/her body position and camera angle. The delete and confirm button will show on screen when the photo is done. Delete button allows user to retake photo and the confirm button when touched will upload the photo to server. The QR code will be displayed in the middle of the screen when photo is uploaded to the server. The page will navigate to Menu page when users touch next or if no response was detected after one minute.

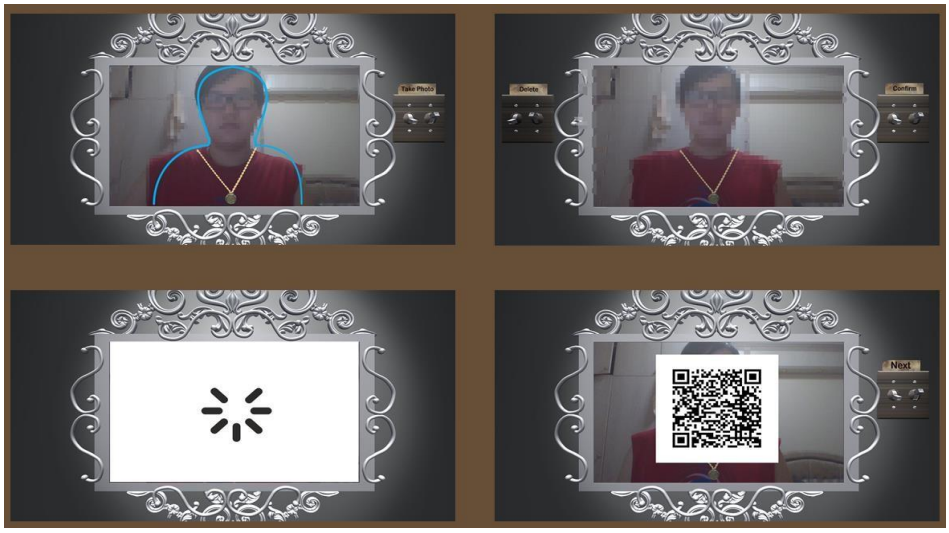


Figure 3.8:Take photo

3.5.1.2 System Development

The goldsmith simulator is developed by Unity3d and Arduino SDK. The system is running on Windows. Unity 3D is used to develop the main system of the simulator. Arduino SDK is used to communicate IR sensor with Unity3D. The development of simulator is following system analysis and design. The following section will explain the development in detail.

The development of simulator can be divided into three parts which are Menu, Main Page and Digital Souvenir. GameObject is one of the important components in Unity3D development. In the development of goldsmith simulation station, all 3D models will be converted to GameObject and attached with C# code. The interaction between GameObject and motion detector is based on Leap Motion SDK. The leap motion SDK provides the tracking data for developers. Developers can calculate tracking data to identify motion from the user.

Menu page is the first page of the simulator. The page includes two scripts which are **UIControl** and **Menu**. UIControl script used to control the game object of scenes and Menu script used to achieve the function of Menu page, such as play video.

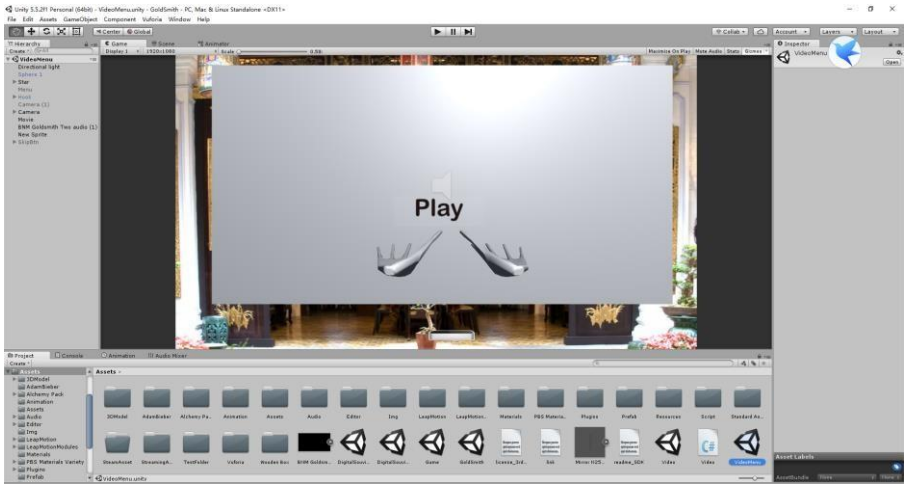


Figure 3.12: Menu development in Unity3D

In the development of Main Game, there have a script called UIControl. UIControl is used to control GameObject in Main Page, such as camera position, animation and button activity. The instruction will be controlled by an audio script. When user selects Start button, the script will launch a simulation.



Figure 3.9:Start Page in Main Game

As described in previous section, the system simulates a goldsmith making a jewellery in four stages. In the first stage, the user needs to pick up one frame and one coin. There are two scripts in the first stage - one is attached to frames and coins. The other one is attached to the pan. In the second stage, the script will be launched and the position of the camera will move to daching when the pan detects one coin and one frame in the detection area. Figure 3.14 shows the change between two stages. When stage 2 is done, it will launch the script of stage 3.

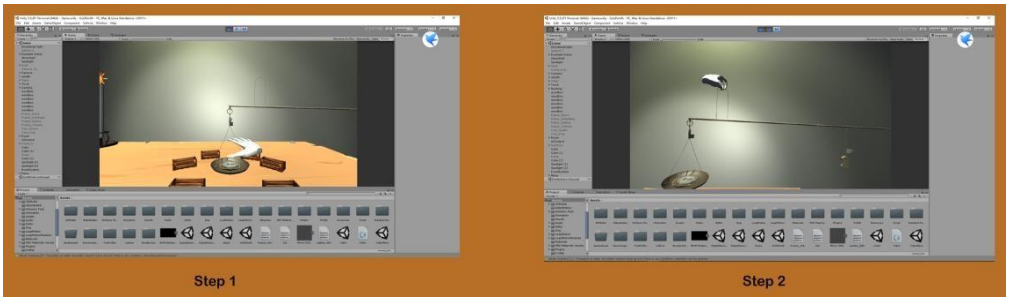


Figure 3.14: The change between stage1 to stage2

The third stage of Main Page is picking up torch gun. The torch gun will turn on after the user pumps on a physical bellows. An IR sensor is placed in front of the bellow to detect the number of times it is being pumped. Figure 3.15 shows the development of Arduino SDK. The IR sensor is connected to Arduino. The communication between Arduino and Unity3D is through a serial port. The protocol allows Unity3D to get data from Arduino. In this section, the main script of stage 3 is used to control game object and another for getting data from IR sensor.

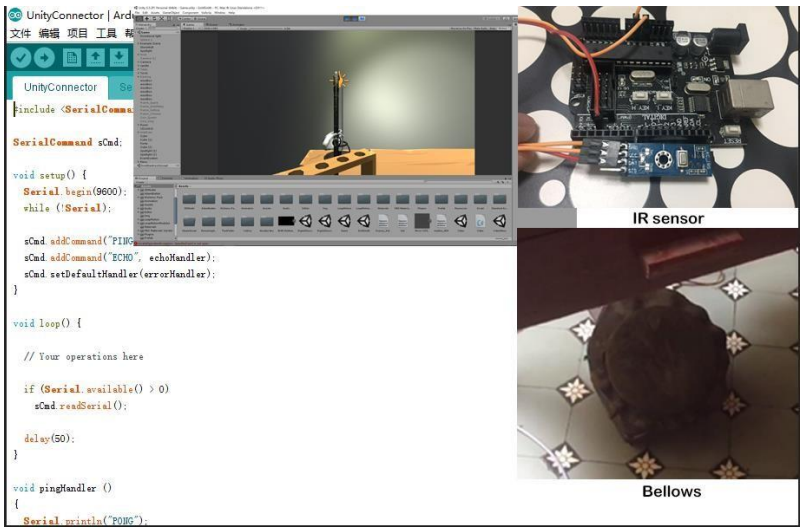


Figure 3.15: Development of IR sensor, used with an air pump bellows

The fourth stage of Main Page is using a torch gun to soldering frame and coin together. The script generates a circle between frame and coin. Figure 3.16 shows the development of stage 4. The user needs to use torch gun to solder gold material. There are two options for the user when they finish soldering. If user select **Try it on**, it will navigate the page to Digital Souvenir.

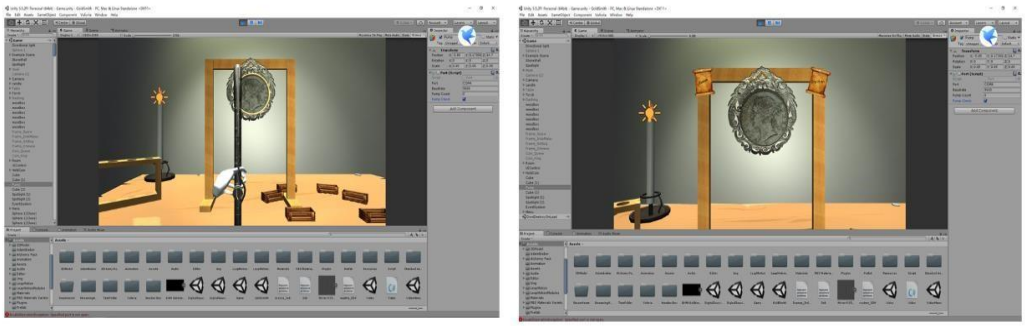


Figure 3.16: Development of Stage 4

In the development of Digital Souvenir, the main script is used to take a photo, upload photo and delete the photo. The server to store photo is provided by Baba Nyonya Museum. The QR code is generated by open source SDK from GitHub.



Figure 3.17: Development of Digital Souvenir

3.5.1.3 System Testing

System testing is an important stage in software development. The testing of goldsmith simulator includes a Unity test and integration test. Unity test is used to test the independent function of the system. Integration testing tests the whole systems. The following section will explain details of testing.

3.5.1.3.1 Unit Testing

Test-driven development (TDD) is one of the development techniques in agile where the function should pass testing before it is integrated into the main system. Figure 3.18 shows unit testing of the project. The following list shows the detail of unit testing:

- **Menu**: The test aims to make sure tutorial video can play and button can work.
- **Pick Up frame and Coin:** The testing of pick up frame and coin needs to check the detection of leap motion and makes sure user can be easy to pick up frame and coin. It also needs to test navigate function.
- **Balance Daching:** The testing of balance daching used to make sure user can easily to pick up daching and balance it. It needs to ensure unity camera will automatically change when daching is balanced.
- **Pick up Torch and turn it on:** The testing needs to confirm users can pick up torch gun are easy and IR sensor can respond in short time.
- **Soldering Frame and Coin:** The testing needs to make sure torch gun can soldering material to frame and coin. It also needs to ensure the button can work.
- **Digital Souvenir**： The testing of digital souvenir needs to check the performance of taking photos. The upload of photo needs finish in short time.



Figure 3.10:Unit testing during pickup frame and coin

3.5.1.3.2 Integration Testing

The integration testing is to ensure the success integration of all functions to main project. The integration testing of the project includes application testing and physical testing. Application testing means to integrate all game functions and test the logical process and bugs in the game. The physical testing is to test out the pump bellows to make sure that the system can get IR data when user pumps on the bellows.

3.5.2 Batu Boh Simulator

Batu Boh is a traditional tool to grind spices in Peranakan cuisine. While in Chinese cuisine, Batu Boh was usually used to ground beans and rice, the Nyonyas extended its use to grind spices. Spice was the biggest industry in the world 500 years ago. Once one of the richest ports on the spice route, Malacca boasts a colourful history spanning Malay sultans, Arab and Indian Muslim traders, Chinese settlers, and periods of Portuguese, Dutch and British colonial rule. The word Peranakan itself translates to 'locally born and bred', and the idea is that the Chinese immigrants of the 15th century married locals and the result was a unique culture with entirely new traditional clothes, beliefs and cuisines. The Peranakan cuisine is influenced by a variety of cultures. An interactive batu boh is developed to allow users to experience and engage with the history of Malacca and Peranakan culture. The following section describes the technical development of the interactive Batu Boh.



Figure 3.19: The original Batu Boh

Figure 3.19 shows an old Batu Boh often used as a spice grinder by Nyonyas to make '*kuih*' or cakes. The design of Batu Boh simulator helps to simulate the process of Nyonya grinding spices for cakes. To use the traditional Batu Boh, users will put ingredients and spices into a hole from the top which would drop to the bottom and turn the handle to grind them. The interactive Batu Boh is designed to allow users to make a '*kuih*', to choose from an option of 4 recipes, each with different cultural influence. Users would drop an ingredient at a time into the interactive Batu Boh to hear cultural stories as they grind and repeat the process until the '*kuih*' is done. To signal the end of *kuih* making, users will be able to smell the fragrance of the *kuih* and finally get a '*kuih*' sticker, released by the simulator in a capsule as a physical souvenir. The smell interface is

included to create an immersive cooking experience for visitors. The interactive Batu Boh is designed as a replica and embedded with IoT technologies to allow users to physically touch and use it (to simulate grinding action), which would not be possible for visitors to touch and interact with the old artefacts found in the museum.

3.5.2.1 System Analysis and Design

The following section will describe system requirements, user case diagram, Activity Diagram, System Architecture and user interface design of the Batu Boh simulator.

3.5.2.1.1 System Requirement

The system requirement can be divided into hardware and software requirement, and functional requirement. The technical requirement lists the minimum hardware and software needed to build the system. The functional requirement specifies task of the system.

The following list is the minimum hardware and software requirement for Batu Boh Simulator:

- Raspberry Pi 3
- Linux
- Servo Motor
- Step Motor
- RFID reader
- RFID Card
- IR sensor
- Internet connection
- Speaker
- replicate Batu Boh
- Python

There are four recipes in the system. Each recipe has three RFID cards to represent each ingredient. The user needs to insert a tagged ingredient card and turn the handle to simulate the process of grinding and mixing of species and other ingredients. The associated instruction and education content will automatically play in an audio format of an old chef re-collecting historical stories associated with the spice or ingredient to

his apprentice. When the simulation is done, users can get a physical capsule as a souvenir.

Table 3.3 shows the functional requirement of Goldsmith simulation system. The functional requirement is identified based on the museum tour meeting with the museum curator.

Table 3.3: Functional requirement

No	Description
FR1	It needs an audio to introduce system to user.
FR2	It should have an IR sensor to count the number of times the handle is turned.
FR3	The RFID reader integrates with step motor.
FR4	It should have a function to drop the RFID Card.
FR5	It should have perfume fragrances for spices.
FR6	It should have a capsule machine controlled by servo motor.
FR7	It should have a server to store audio files.
FR8	The audio file is controlled by RFID card.
FR9	The system should exit the simulation when user leaves.
FR10	It needs a log file to record user behaviour.
FR11	The speaker value should be loud enough.

3.5.2.1.2 Use Case Diagram

User case diagram is used to represent the interaction between the user and system. There are two actors in the project - user and server. The following Use Case Diagram demonstrates that the relationship between different functions and user (see Figure 3.20 and Table 3.4).

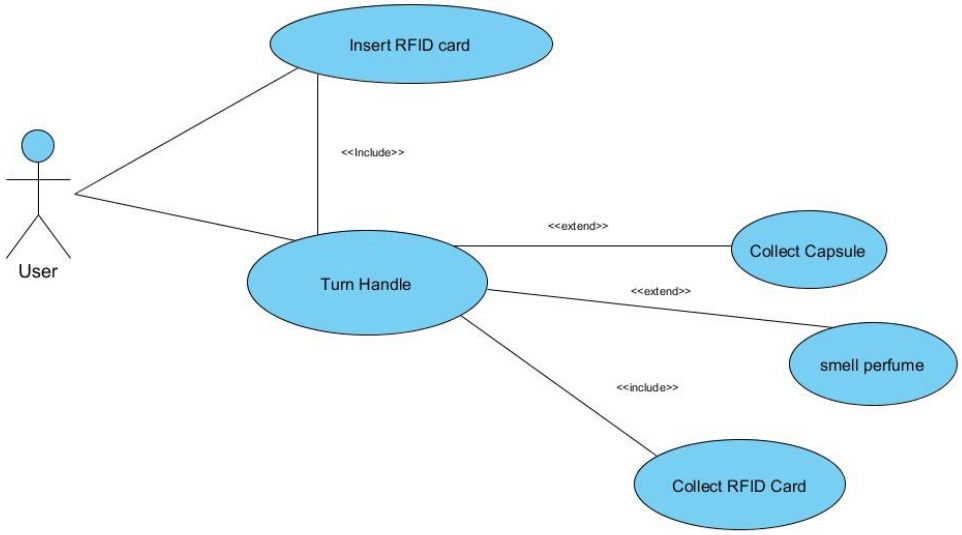


Figure 3.20: Use Case Diagram

Table 3.4:Relationship between use case and User

No	Use case	Relationship	Description
UC1	Insert RFID Card	Association && Include UC2	User insert RFID card to system and get an audio instruction.
UC2	Turn Handle	Association && Extend UC 3 && Extend UC4 && Include UC5	User need to turn the handle to simulate the process of grinding species.
UC3	Collect Capsule	Association	User can collect a capsule as souvenir when simulation is done.
UC4	Smell Perfume	Association	User can smell the spice when simulation is done.
UC 5	Collect RFID card	Association	User collects RFID card and return to rack.

3.5.2.1.3 Activity Diagram

Activity diagram shows the dynamic behaviours of the system. It presents the flow from first activity to the last one. Activity Diagram shows the workflow of the whole project (see figure 3.21). The following section will explain each activity of activity diagram.

The Batu Boh simulator starts with a **tutorial audio**. The tutorial audio will ask user to choose one of the recipe cards from the kitchen table and insert Ingredient cards one at a time into the Batu Boh. After the user inserts an ingredient card, he/she will need to turn the handle to activate a story **audio** which will introduce the recipe and related cultural stories. Ingredient cards will drop down to the bottom of the hole when the audio is finished. The process of inserting cards and turning the handle will repeat until the user inserts the last ingredient card. At the end, it will release a capsule and spray the cooking fragrance associated with the '*kuih*' the user is making. This activity is controlled by a servo motor. In addition, the system will automatically reset back to 'start' when user leaves.

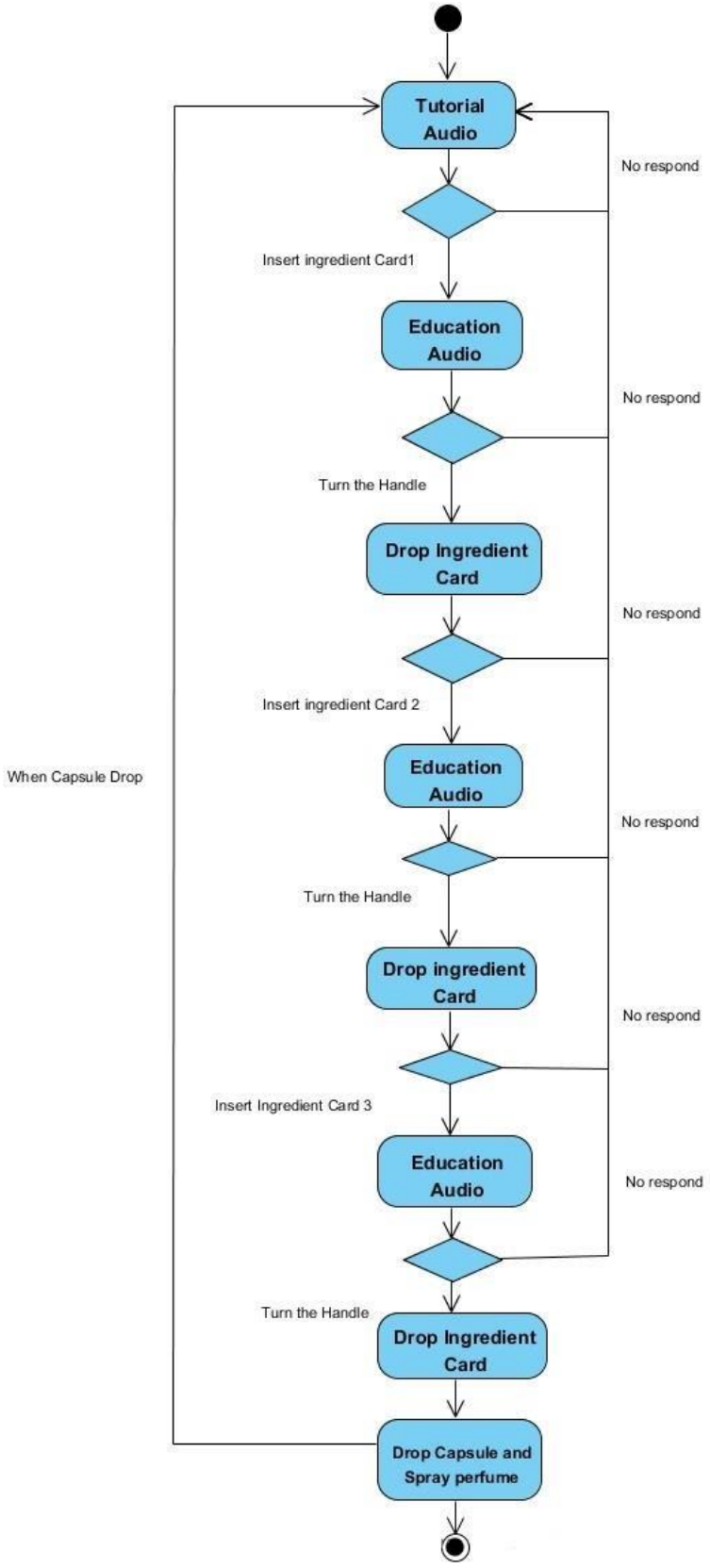


Figure 3.21: Activity Diagram of Batu Boh simulator

3.5.2.1.4 System Architecture

This section explains the architecture of Batu Boh Simulator. Raspberry pi 3 is the core of Batu Boh simulator. Raspberry pi 3 is a single board computer that provides GPIO pins for different sensors and motors. The following part will explain the functions of different components.

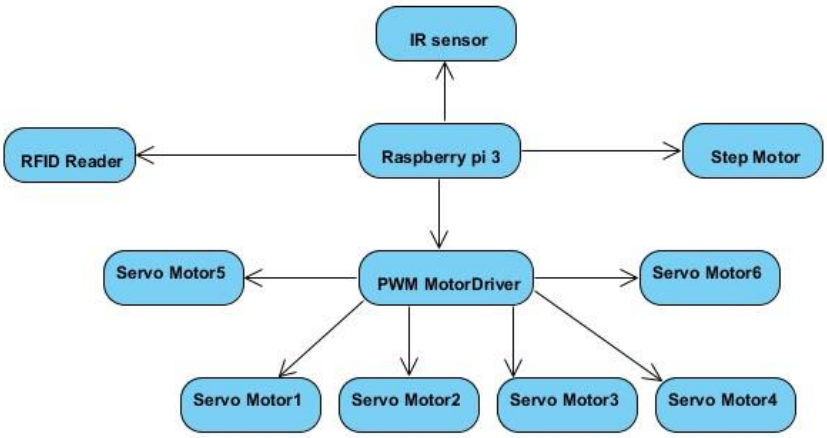


Figure 3.11:Hardware architecture design

Figure 3.22 shows hardware architecture design of the system. The sensors and motors are connected to Raspberry pi 3 pins through jump wires. In the software development of Batu Boh simulator, Raspberry pi 3 communicates with sensors and motors through python script. All the sensor and motors are controlled by independent function script. The main script is used to control the logical part of systems.

The sensors and motors are embedded into the replica of a Batu Boh and a cabinet, which serves to store capsules and is connected to the Batu Boh. RFID reader, IR sensor and step motor are embedded to replica of Batu Boh. RFID reader is used to read the ingredient cards and step motor is used to open a flap to drop the ingredient card into the Batu Boh. IR sensor is used to count the number of times the handle is turned. PWM motor driver and servo motor are embedded inside the capsule cabinet box. It used to release capsules and spray cooking fragrance at the end of the user interaction with the system.

3.5.2.1.5 Physical design of Batu Boh

The physical design of the interactive Batu Boh was carried out in two phases, with the help of a local craftsman. Figure 3.23 shows the design prototype of Batu Boh. The

development of phase one focussed on the exterior design to take the look, shape and functionality of the actual batu boh artefact to suit the museum environment. In phase two, the capsule box was designed together with its internal mechanism. it will design Batu Boh and Capsule Box with interior design. The following section will describe the exterior design in phase two.

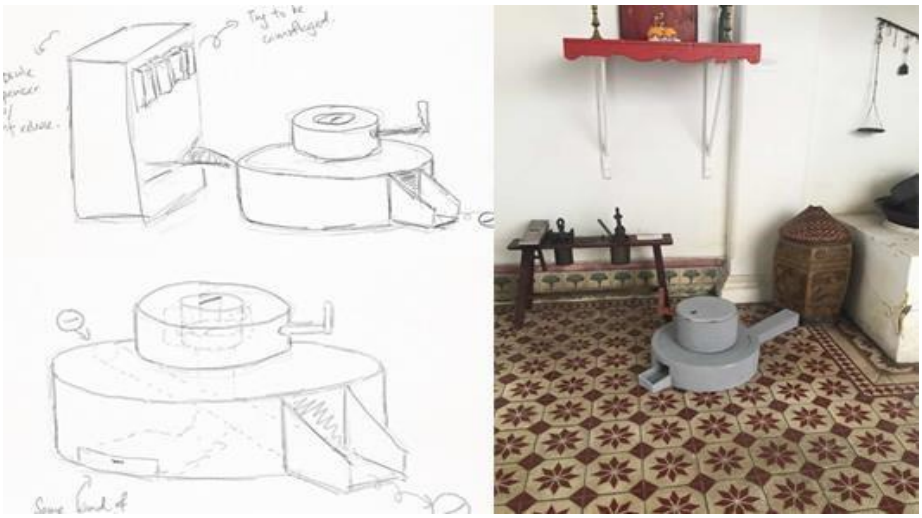


Figure 3.12:Prototype design of Batu Boh

The design of Batu Boh is separated into top part and base part as shown in figure 3.24. The exterior of Batu Boh is made of woods. The top part of Batu Boh consists of a hole for slotting in the tagged cards. The hardware is hidden in the base part. In the base part of Batu Boh, it has a tunnel tube to receive released capsules from the capsule box. Figure 3.25 shows the exterior design of capsule box. Servo motors are used to release the capsules and remain hidden in the capsule box.

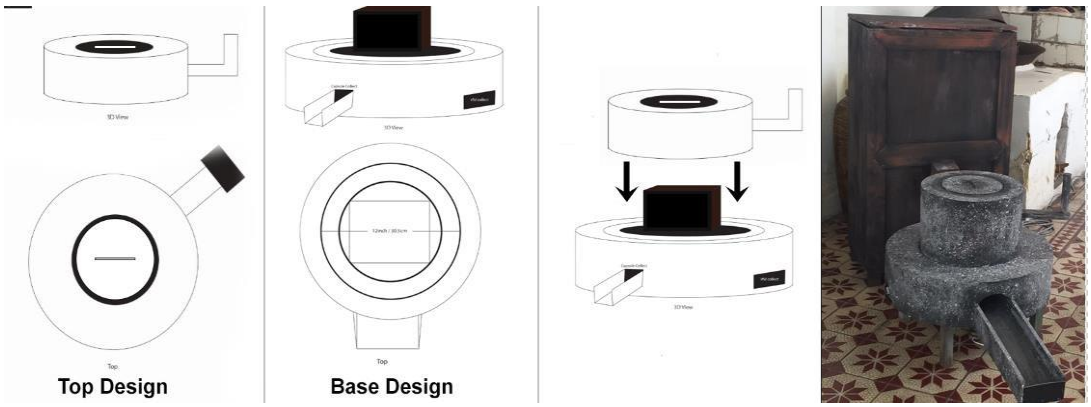


Figure 3.13:Exterior design of Batu Boh



Figure 3.14:Exterior design of capsule box

3.5.2.2 System Development

In the development of the Batu Boh replica, the research team provides the physical design of Batu Boh to the craftsman. Therefore, the development of hardware and software can be done at same time. The sensors and motors embedded into the replica during the testing stage. Figure 3.26 shows the interior design of Batu Boh simulator and Capsule Box.

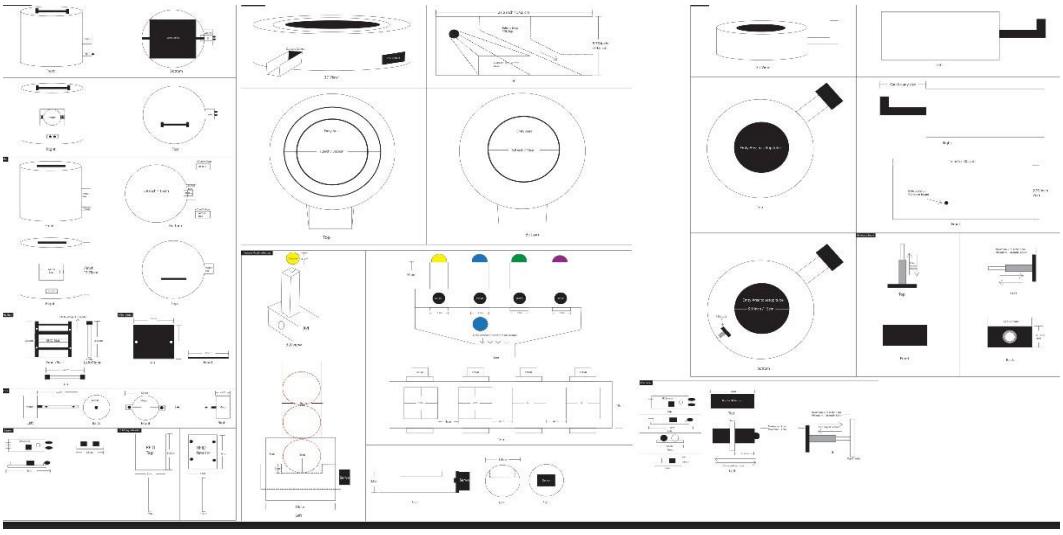


Figure 3.15:Interior design of Batu Boh and Capsule Box

The Batu Boh simulator will be a long-term exhibit in the Baba Nyonya Heritage Museum. Therefore, the hardware of system is divided into many components. The multiple

component structure is better for maintenance in the future. Each component is programmed to be controlled by an independent function. In addition, the logic and data processing of systems is controlled by the main script. The following list is the python function for each component of the system:

- **ReadIngredients**：The function of **ReadIngredients** is used to control RFID reader. The function will return Ingredient card information to the system.
- **StepMotor:** The **StepMotor** is used to control StepMotor. StepMotor will drop the RFID card when RFID reader stops reading data from RFID card. The function can control the clockwise and anticlockwise rotation of the motor. The function of StepMotor has one parameter, 1 is clockwise and -1 is anticlockwise.
- **IRcheck:** The **IRChcek** is used to get data from IR sensor. The sensor will return false and true data to the system. The function of IRcheck is used to detect turning of the handle.
- **Set_servo_pulse:** This function is used to control PWM driver board. PWM driver Board is an electric board that controls multiple servo motors. It can control maximum 16 servos motor at the same time. In this project, Servo 1 to Servo4 is used to control capsule machine. Servo 5 and Servo 6 is used to control perfume machine. There are two parameters which are channel and pulse. Channel uses to drive up specify number of the servo motor. Pulse is used to control the rotation of degrees.

In the main script of Batu Boh simulator, the programming logic follows the Activity diagram. In addition, the audio is stored in the museum server. The museum can upgrade the system's recipe by replacing the audio files. The script of system uses Pygame library to play audio and log behaviours. Figure 3.27 shows the main script.

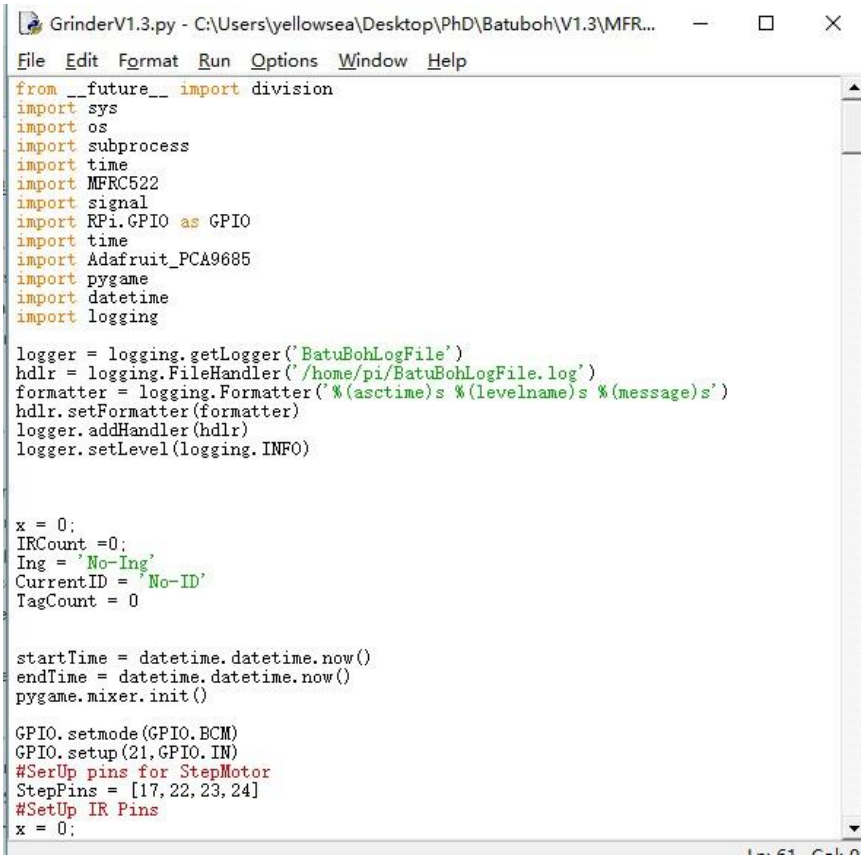


Figure 3.16:Python code of main script

3.5.2.3 System Test

System testing is one of the important stages in software engineering. The testing of Batu Boh simulator involves the unit test and integration test. Unity test is used to test the independent function of the system. Integration testing is used to test the final version of the simulator. The following section will explain the testing.

3.5.2.3.1 Unit Test

TDD is a development technique in agile where a function should pass the testing before being integrated into the main program. The unit test is widely implemented in Test-driven development (TDD). In the project of Batu Boh simulator, the system is divided into four components: RFID reader, IR sensor detection, capsules machine and fragrant machine. Figure 3.28 shows the photo during the Unit test. The following list describes the test of four components:

- **RFID Reader:** The test of RFID reader ensures the hardware has enough space for RFID detection and drop to collect point. In addition, it needs to ensure step motor has enough rotation to drop RFID card.
- **IR sensor detect:** The test of IR sensor is used to check detection distance between sensor and handle. It needs to ensure sensor can detect the handle.
- **Capsules Machine:** The test of capsules machines is to ensure capsule can drop to the tunnel tube in Batu Boh. In addition, it needs to adjust rotation degrees of servo motors.
- **Fragrant Machine:** The test of fragrant machine is to ensure cooking fragrance can be sprayed. In addition, it needs to adjust the rotation of servo.

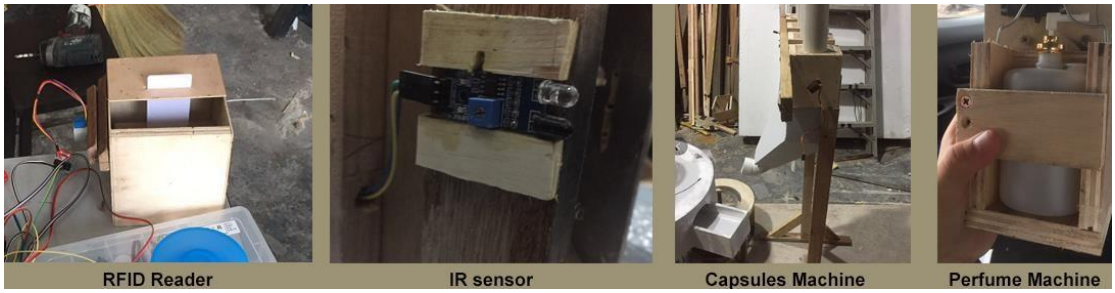


Figure 3.17:Unit Test

3.5.2.3.2 Integration Test

The integration testing was done together with the craftsman. The integration testing will test the hardware with main script. In addition, Integration test allow us to fix bugs of the system and solve hardware issue. Figure 3.29 shows craftsman fixing a hardware issue during integration testing.



Figure 3.29: Craftsman solving hardware issue

3.6 Evaluation and Result

3.6.1 Experimental Setup

The evaluation was carried as part of a public exhibition at the Baba Nyonya Heritage Museum. The evaluation aimed to test the stability and usability of developed interactive exhibits – the Goldsmith and Batu Boh simulators. In this initial evaluation, the project was also interested to determine outcomes in terms of learning gains among visitors.



Figure 3.18:Public user trial

The evaluation was carried out based on user observation and questionnaires. The evaluation involved 30 participants from 10 experimental small groups. The group size is between 1 to 6 participants. The age range of participants is from 9 to 47 years old, while the age of the children is from 9 to 17 years old. Four experimental groups were residents of Malacca city.

3.6.2 Result

The questionnaires have two parts - pre-test and post-test questions to find out how much participants know about the history of Malacca and Peranakan culture. The first section of the post-test questionnaire would test the knowledge of participants after

having interacted with the interactive exhibits to determine outcomes of learning gains. The second and third section compares the performance between Goldsmith station and Batu Boh simulator in terms of their ability to encourage reflection among participants. The last section was to get feedback on user experience while interacting with the exhibits. The following section summarises the result of evaluation.

3.6.3 Learning Outcome

The first section of post-test results is compared with pre-test results. In the pre-test, there are ten questions to measure the existing knowledge of participants. In the post-test, it uses the same knowledge questions to evaluate learning effect. In the design of questions, questions are related to traditional museum tour, Batu Boh simulator and goldsmith simulator.

Figure 3.31 shows the results of pre-test between correct answer, wrong answer and unsure answers. The percentage of correct answers is 54% before starting the museum tour. The percentage of unsure answers and wrong answers are 22% and 24%. From the results of post-test, the percentage of correct answer increased from 54% to 82% (see Figure 3.32). Most of the wrong answers from the post-test survey are related to traditional museum tour and goldsmith simulator. In conclusion, the survey results show that that the Batu Boh simulator supports better learning gains than the Goldsmith simulator.

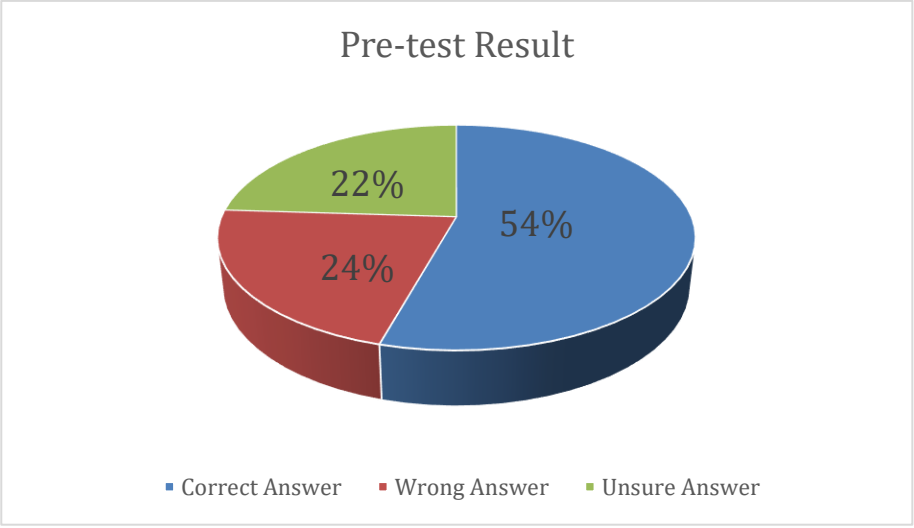


Figure 3.19:Pre-test Result

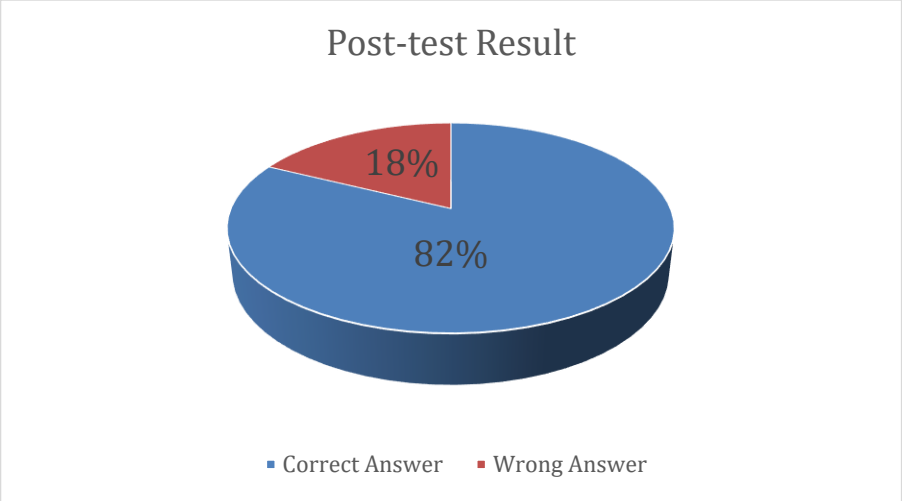


Figure 3.20:Post-test Result

3.6.4 Comparison

The following table 3.5 lists the comparison questions and results between Batu Boh simulator and Goldsmith simulator. Participants choose a preference score from 1 to 7 which represents strongly disagree to strongly agree. The questions were asked to gain feedback on participants' learning experience, and reflections. From the results of five questions, the Batu Boh simulator scored a higher percentage (in agree and strongly agree) than the Goldsmith simulator in terms of its ability to provide a good learning experience, and help participants gain more knowledge and reflect on their own culture.

Table 3.5:Comparison Question (1-strongly disagree, 7- strongly agree)

No	Questions
1	The exhibit provides a good learning experience of the Baba Nyonya culture.
2	The exhibit encourages discussions with others
3	The exhibit helps me reflect/think more about my own culture
4	The exhibit wants me to learn more about the Baba Nyonya culture
5	The physical interaction with the exhibit enhances my learning experience
6	I felt that I have gained more knowledge after using the exhibit

Table 3.6:Comparison Result

	Strongly disagree		Disagree		Somewhat disagree		Neither agree or disagree		Somewhat agree		Agree		Strongly agree	
	GoldSmith	Batu Boh	GoldSmith	Batu Boh	GoldSmith	Batu Boh	GoldSmith	Batu Boh	GoldSmith	Batu Boh	GoldSmith	Batu Boh	GoldSmith	Batu Boh
Q1	0	0	0	1	5	3	3	1	4	4	7	7	11	14
	0%	0%	0%	3%	16.67%	10.00%	10.00%	3.33%	13.33%	13.33%	23.33%	23.33%	36.67%	46.67%
Q2	3	4	1	2	2	2	4	1	3	4	5	2	12	15
	10.00%	13.33%	3.33%	6.67%	6.67%	6.67%	13.33%	3.33%	10.00%	13.33%	16.67%	6.67%	40.00%	50.00%
Q3	2	1	0	1	3	1	4	3	4	3	5	5	12	16
	6.67%	3.33%	0.00%	3.33%	10.00%	3.33%	13.33%	10.00%	13.33%	10.00%	16.67%	16.67%	40.00%	53.33%
Q4	2	0	1	1	2	1	4	7	3	0	8	7	10	14
	6.67%	0.00%	3.33%	3.33%	6.67%	3.33%	13.33%	23.33%	10.00%	0.00%	26.67%	23.33%	33.33%	46.67%
Q5	2	0	0	1	2	1	3	3	5	3	7	8	11	14
	6.67%	0.00%	0.00%	3.33%	6.67%	3.33%	10.00%	10.00%	16.67%	10.00%	23.33%	26.67%	36.67%	46.67%
Q6	1	0	0	1	3	3	2	0	5	3	6	7	13	16
	3.33%	0.00%	0.00%	3.33%	10.00%	10.00%	6.67%	0.00%	16.67%	10.00%	20.00%	23.33%	43.33%	53.33%

3.6.5 Experience

Section 4 of the post-test survey allowed participants to provide open-ended feedback on their user experience. In question 1, user feedback showed that participants had good experiences using the systems. The result of the second question based on answers from participants, seventy-seven percent of participants thought that the Batu Boh simulator is better than the Goldsmith simulator. According to the feedback of question 3, participants suggest increasing audio value, giving more instruction and add more interaction between users.

Table 3.7:Question1 Result of user experience survey

Feedback	How did you feel about using the exhibits and what challenges you faced?
1	User Interface is friendly
2	Fun and learn a lot.
3	Audio value too soft
4	I felt amazing by the technology used for exhibits
5	The exhibits are good but sound too soft
6	Interesting way to engage learning. It's hard to control motion detector
7	The exhibits are interesting and interactive. 1. Detector problem of goldsmith 2. Audio issue
8	Goldsmith is not easy to control at start, not friendly, but once it was explained by a guide, it was easy to control.

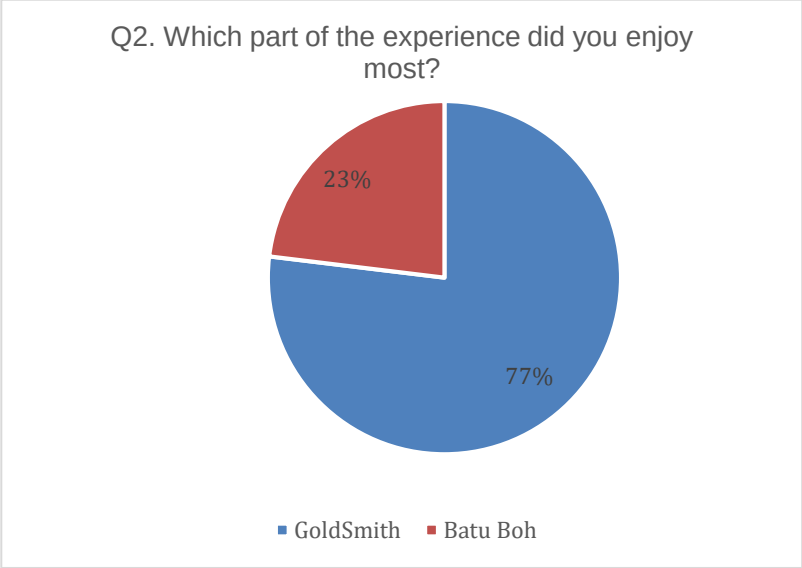


Figure 3.21:Question 2 Result of User experience survey

Table 3.8:Question 3 Result of user experience survey

Feedback	What other feedback and recommendations do you have to improve the experience?
1	More instruction given. Make the Batu Boh talkative/ less repetition of instruction. I recommend that more signboards with introduction are used.
2	More physical interaction
3	Having more fun interactive exhibits to gain more knowledge about the Baba Nyonya culture
4	Audio is lacking, can be improved more.
5	Better can have more exhibits for family. Or do create some exhibits for more than one child
6	Better have different languages for exhibits
7	Need more instructions Excellent work.

The following table summarises the results of observation from evaluation:

Table 3.9:Summary of observation

Station	Observation
Goldsmith	1. Adults were confused about the Goldsmith station. 2. The 2 actions part (lighting the torch from the candle) was hard specifically for younger age children to coordinate both hand with legs while pushing and needing to adjust with their height. 3. Also, it was harder for younger children to be more accurate at soldering the coin frame even though they liked the action itself. While the older children and adults seemed to do better. 4. Picking up the coins at the beginning was the easiest and the most interesting part. Also, taking the picture. 5. Most children loved the augmented reality pictures at the end.
Batu Boh	1. Most of the children and even adults too were excited to use Batu Boh exhibit to grind and make the recipes. They enjoyed the funny narration. Also, the station attracted a lot of bystanders (other visitors) 2. At the end when they received physical capsules as souvenirs, they expected the *kuih* sticker to be the same recipe they made. 3. The fragrant cooking smell released received a lot of positive comments by both children and adults. 4. The ingredients of each recipe need to be marked as users mixed up the tagged cards with other recipes. 5. The grinding part was a lot of fun yet some was tired or commented it was too long (Some grinding loops were up to 10 so maybe if it can be minimised so it would be more efficient). 6. The capsules could be colour-coded with recipe cards. The children were excited to receive the capsules but not about the prize in it. 7. The position of the Batu Boh shifted after being used several times. As a result, the released capsule would fail to drop into the tunnel pipe8. All in all, the Batu Boh exhibit was the most successful one for both children and adults where some people even tried it several times.

3.7 Conclusions

In the first phase of research, two exhibits have been developed. It was found that the Goldsmith and Batu Boh simulators were able to enhance learning using motion detection and Internet of Thing (IoT) technologies. In the next phase of research, the

research planned to solve issues from the above pilot project. The results of evaluation showed that most of the participants felt that the current exhibits fail to support much communications and discussions among group members. Currently, serious game is normally implemented in computers and mobile devices. In the following research, the research planned to integrate serious game elements to current research project to include more engaging storyline, reflective strategies and to support multiple users. The hypothesis was by incorporating serious games to be used with IoT-based smart replicas will encourage meaningful and deeper cultural reflections among players.

Finally, it planned to summarise the experience of designing IoT games as a design guideline. Currently, there are two types IoT solutions in museum digitisation. One of the solutions is using integrated sensor network with museum service, such as in lighting control and digital tour guide. The other solution is using integrated RFID tags with 3D printing to create smart replicas to trigger audio instructions. The pilot project provided the basis for further exploring the potential of using IoT technologies to increase physical user interaction with artefacts to aid cultural reflection.

Chapter 4. IoT Serious Game

Having learned from the pilot study, a second user trial was conducted and reported here with the aim of extending the learning experience of visitors to further support reflection and social experience through serious games and IoT concepts. The project continued to work closely with museum curators from the Baba Nyonya Heritage Museum to carry out design iterations on the exhibits and interactive tour (see figure 4.1).



Figure 4.1:Discussion Meeting with Baba Nyonya Museum

Based on the results of pilot evaluation, it was found that the interactive installations were able to enhance visitor engagement, but evidence of cultural reflection was still limited. The following provides a summary of the results:

- Batu Boh Simulator provided better learning experience compared to Goldsmith Simulator.
- Participants preferred interactive installations that have more physical interactions.
- Limited communication and discussion during tours were observed.
- Multisensory experience through smell had little impact on visitor discussion and reflection.
- Physical souvenirs did not play a huge role in encouraging discussions on culture but were able to increase visitor engagement.

- There were only a few cases where participants showed evidence of low level reflection and discussion.

4.1 Project Goals

In the main museum study, the research aimed to address the problem of supporting cultural reflections in addition to informal learning during museum visits by integrating elements of Internet of Things (IoT) and games into the visiting experience.

Previous studies have shown that potential benefits of games include improved self-monitoring, problem recognition and problem-solving, decision making, better short-term and long-term memory, and increased social skills such as collaboration, negotiation, and shared decision-making (Liarokapis and de Freitas, 2010). Previous research has suggested that serious games can help visitors gain better understanding and interest in cultural learning (Rubino et al., 2015; Anderson et al., 2010; Aguirrezabal et al., 2014). Currently, research on serious games is still limited to mobile and desktop games where users often learn about culture and history from the vicinity of their homes (Tarja et al., 2007; Coenen, Mostmans and Naessens, 2013; Antoniou et al., 2013). As such this project focused on exploring a new physical IoT approach to designing cultural serious game experience in museums. By integrating IoT technologies into the game experience, it has potential to create interactive user experiences that revolutionise the way people interact with their environment and the objects within it by creating a ubiquitous network of physical devices (Li, 2017). While there may be some research projects that support reflective experiences through games and IoT systems, respectively, there is still limited research in this area as to how designers may combine both and design IoT serious games that will evoke deeper, cultural reflections to help shape community identity.

In order to achieve this project goal, the project applies the reflection framework by Fleck and Fitzpatrick (2010) in the design and evaluation of the main museum study in order to achieve all levels of reflection to include transformative and critical reflections. The project adapted the reflection framework for use within the cultural museum context as follows:

- Level 1 Description reflection: The first level reflection should provide basic knowledge to participants. The technology should provide informational content to build the base knowledge of a topic. In this research, participants should receive basic knowledge of the culture to include the historical origin, tradition and customs of the Peranakan culture in order to trigger descriptive reflection.

- Level 2 Dialogic reflection: The second level reflection should provide deeper knowledge related to background information. The technology should allow participants to explore the relationship between the history and artefact or exhibition.
- Level 3 Transformative reflection: The third level of reflection involves participants developing new or deeper understanding of culture that could change their existing beliefs. The technology should present rich and multiple perspectives to help participants see things in new ways or in ways that they did not expect.
- Level 4 Critical Reflection: The highest level of reflection culture involves participants thinking more than culture. The technology should allow participants to extend their thinking to wider societal topics.

4.2 Design Goals

In order to achieve the project goals in the main museum study, the project identified and defined seven design goals which served as design requirements to be met. The design goal (DG) 1 to 3 aimed to trigger level 1 and level 2 reflections, while the design goal 4 to 7 aimed to achieve level 3 and level 4 reflections.

- DG1 - Connecting past with present: The design goal aimed to provide background of culture (level 1 reflection) and deeper learning to participants (level 2 reflection). By connecting past with present will help participants understand the origin of Peranakan culture. Participants can compare past with present to understand how the culture has remained the same or become different.
- DG2 - Supporting role-play for self-immersion: The design goal aimed to guide participants to extend basic knowledge (level 1 reflection) to deeper understanding of culture (level 2 reflection) through role-play opportunities. Role-play provides an immersive experience for participants to experience the Peranakan daily life.
- DG3 - Bridging physical and digital world: The design goal aimed to combine physical and digital technologies to support a mix of physical and digital interactions to support basic learning (level 1 reflection) and deeper learning (level 2 reflection).

- DG4 - Personalization of artefact: The design goal aimed to help participants make connections with the museum content and artefact by allowing them to personalize these content or items to be used as part of the museum experience. The personalization activity will in hope help participants reflect at a personal level that might trigger high level of reflections (level 3 or 4 reflection).
- DG5 - Providing physical interaction for engagement: The design goal aimed to increase participant engagement with augmented artefact through physical interactions. The physical interaction also served to support a shared group experience to encourage discussion among family members. The discussion helped participants analyse cultural relationships (level 3 reflection) and in wider cultural context (level 4 reflection).
- DG6 - Creating opportunities for sharing thoughts: The design goal aimed to encourage participants to reflect upon their museum experience and explore the relationship between culture and themselves. Their thoughts could trigger other participants' thoughts too where they might learn from each other's perspectives and lead to sharing of other topics relevant to the Peranakan culture such as family and economic structure (level 4 reflection).
- DG7 - Providing physical souvenirs for post-visit reflection: The design goal of physical souvenirs aimed to help participants remember their museum experience and continue with family discussions after the tour. Participants could also use the souvenirs to start a conversation with other people (level 3 or 4 reflection).

4.3 Design Iteration

In the second phase of the research project, new interactive exhibit ideas were brainstormed and developed. The improved museum experience now included three new exhibit ideas based on IoT and serious games approach in addition to existing two exhibits (Batu Boh and Goldsmith). The museum game experience was re-designed to support the process of learning to include a pre-learning and post-learning game, and a new interactive installation involving lantern projection mapping.

In the pilot project, the two interactive installations were setup independently and separate from each other (see figure 4.2). In the new design iteration, all interactive game exhibits were connected to a central server and with an engaging story line.

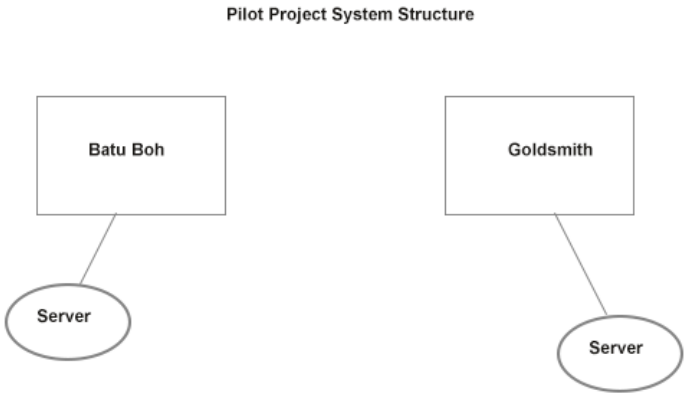


Figure 4.2:System structure for pilot study

Figure 4.3 shows the new system structure. The whole system consisted of five exhibits and one backend server. Similar to pilot project, Unity was used as the cross-platform development tool. The pre-learning game and post-learning game were developed as web-based serious games using Unity3d and run on webGL. The lantern project was developed using Raspberry Pi and was implemented using OpenCV to program the projection mapping. The backend system was developed using Laravel which is a famous php framework and hosted on Google Cloud Service.

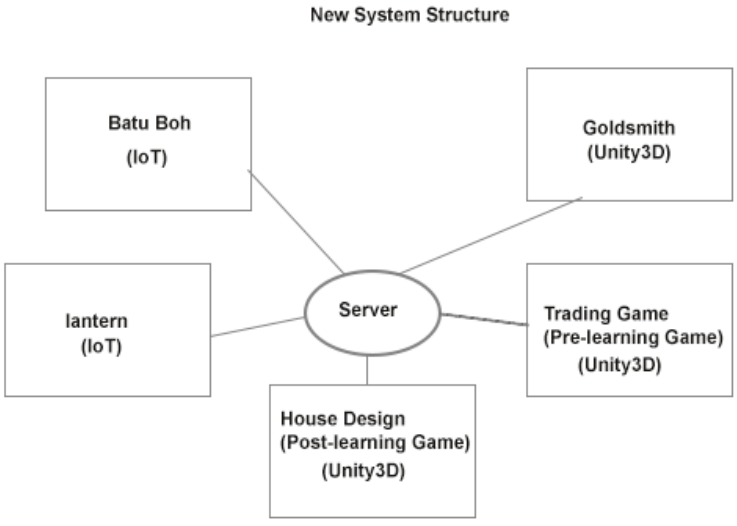


Figure 4.3:IoT system structure for main museum study

4.4 IoT Serious Game Design and Development

4.4.1 Storyboard and Exhibit Design

The storyboard for the second design iteration of museum game experience involved linking the past history of Malacca as a trading port in the 15th century with the museum visiting experience. The museum experience connected all the interactive stations starting from a pre-tour game station for visitors to learn the historical context and origin of the Peranakan culture. Players took on the role of a businessman/woman or trader who is engaged in trading business during the 15th century and wanting to buy a house to settle down in Malacca. Each player needed to make profits from the trading activity with different countries through a web-based trading game before obtaining enough profits to purchase a house in Malacca. When this was accomplished, players could visit the museum and start the self-guided game tour using a map as guide to collect various virtual items e.g. furniture to decorate the new virtual house. The museum tour required players to interact with three interactive game exhibits, with each station linked to the backend server (see figure 4.4). Players needed to carry out specific physical task e.g. make a virtual jewellery to generate a code once completed to collect the virtual item for their virtual house. Players could decorate their virtual house based on these collected virtual items at the end of the tour. The final design of the house could be printed and kept by players as physical souvenirs. The following describes the idea behind each of the interactive game exhibit/station:

Trading Game – Players needed to select an initial country to start from (see figure 4.5). After that, they would need to buy batches of goods from their country of origin and trade them in Malacca. While in Malacca, players would need to trade with other businesses (from different countries). They could learn about each item and its price before deciding to buy. Then, they would bring the traded goods back to their home port, which allowed them to sell at a higher price. The trading between Malacca and the home port continued until the player earned enough profits to buy a (virtual) house in Malacca for 3000 gold coins. They could then start the museum tour to collect virtual artefact e.g. furniture for decorating their virtual house after the tour.

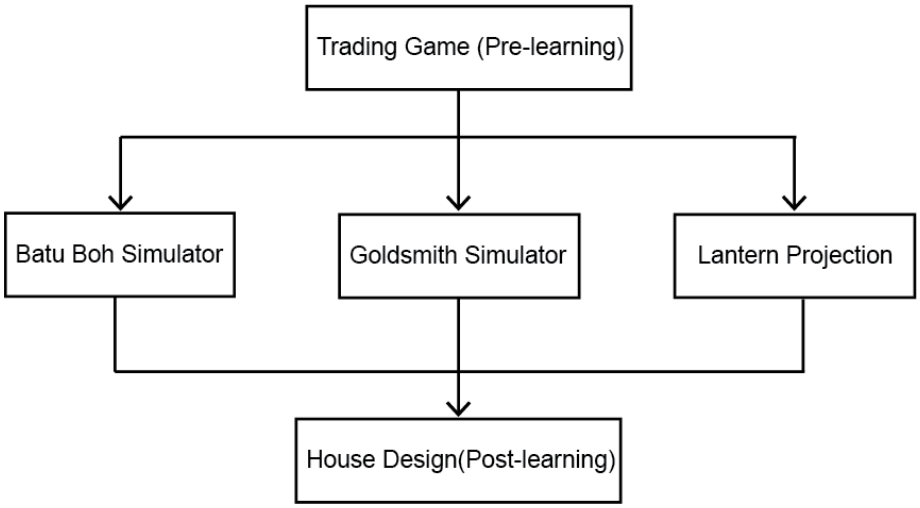


Figure 4.4:Workflow of second iteration.



Figure 4.5:Trading Game

Lantern Design and Projection – The game station allowed players to design and colour in their own lantern, within the lantern shape outlined on a piece of paper. Their physical lantern design could then be scanned and projected onto a real antique lantern hanging from the wall for all visitors in the room to see (see figure 4.6). The lantern projection mapping used computer vision and projection mapping techniques. The lantern projection mapping system included three components which were log in, image processing and data processing. The login function was used to record user data and communicate with the backend server. After the player logged in the system, the system captured the pattern of the lantern (image processing) from the paper and projected it onto the physical lantern and uploaded to backend server (data processing function). Users could access their lantern design by logging in to their virtual house.

Goldsmith simulator – The goldsmith simulator used Leap Motion, an infrared device to detect the player's hand and guide them through the jewellery making process by allowing them to take on the role of an early goldsmith. To start, players used gestures to select a pendant frame and then a virtual coin. In order to start a 'fire' in the solder, players needed to step (pump) on a physical bellow to start the solder 'fire'. Then, they would use the solder to solder together the virtual pendant frame with the coin. Lastly, visitors would have an opportunity to photograph themselves wearing the soldered jewellery as a digital souvenir (see figure 4.6 (Bottom)).



Figure 4.6:Lantern Projection (Top). Goldsmith simulator (Bottom)

Interactive Batu Boh grinder – The interactive Batu Boh was designed as a replica of an old stone grinder, historically used by Nyonyas to grind and mix spices and other ingredients. By embedding it with sensors, users could insert a RFID tagged ingredient card and turn the handle to simulate the process of *kueh* making, while at the same time listening to a recreated audio recording of an old chef re-collecting historical and cultural stories associated with the ingredient. The process is repeated until all ingredients (three) have been "grinded", and a fragrance of the *kueh* is released via a spray along with a physical capsule (containing a sticker of the *kueh*) as a physical souvenir (see figure 4.7).



Figure 4.7:Interactive Batu Boh grinder (Top). Virtual House Design (Post-learning) (Bottom).

Virtual House Decoration (Post-learning) - When a player logged in to his/her virtual house, she/he could see the collected virtual furniture from the tour and use them to decorate the virtual house. They could annotate their design with text and print it as a physical printed souvenir. The furniture collection was done via scanning QR code collected during the tour and associated them with the user ID.

4.4.2 IoT Serious Game Architecture

This research presented a new approach to develop serious game with IoT technologies. Serious game has been implemented to enhance museum learning experience in previous research. IoT is a concept that allows the system to connect everything with internet. With the implementation of a IoT serious game architecture as shown in figure 6.8, it provides a way to integrate all physical exhibits with the virtual game.

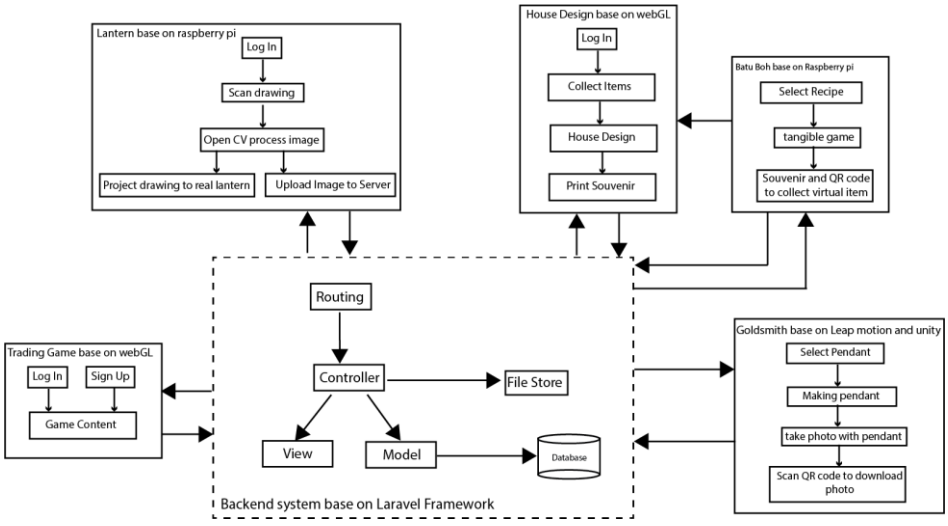


Figure 4.8:System Structure

The IoT serious game system consisted of five interactive game exhibits connected to a back-end server. The back-end-server is the core component that handled data exchange between the virtual game and physical exhibits. It played an important role in the IoT serious game design. As shown in figure 4.8, the back-end server consisted of a MVC model, database and file storage. The system connects different exhibits through the database and file storage components. In the back-end server of IoT serious game, the MVC framework verifies user data from database and maps the user data with their personalised resources in the file storage component. For example, at the start of the first pre-learning game station, the player was required to sign up an account in the trading game. Similarly, player would need to login to lantern projection mapping project before they could scan the lantern design paper to be uploaded to the file storage component and mapped to user database. At the end of tour, user also had to login to the virtual house game before they could access the associated virtual lantern to decorate the virtual house.

In previous studies, many technologies have been applied to develop serious games. There are two popular ways where serious games have been developed either using tangible interfaces or VR/AR. Tangible interfaces is an effective way to engage museum visitors, but often as a standalone installation which can provide only limited information. For example, the Mesch project that integrates a tangible user interface with IoT technology allows visitors to play stories of artefact using RFID tags (Marshall et al., 2016). However, it does not provide a solution to connect all ‘things’. In contrast, the main museum project showed how different exhibits could be integrated through an IoT serious game architecture. For future development, the flexibly of IoT serious game framework allows game designers to add more physical exhibits to the setup, thus more smart objects to the house decoration game. In addition, conventionally if museum curators would like to add a new game content to a physical exhibit, the curator would need technical support to replace e.g. an audio content. With the features of IoT serious game framework, the curator can update the game content from a website. The IoT serious game concept helps to enhance the system expandability.

4.4.3 Online Trading Game (Pre-learning Station)

4.4.3.1 System Requirement

The system requirement for online trading game can divided into hardware and software requirements, and functional requirement. The hardware and software requirements list

the minimum requirement of the system. The functional requirements explain specific task of the system as shown in table 4.1. The following list is the minimum hardware and software requirement for online trading game: 1) Browser support WebGL, 2) 2GB RAM, and 3) Internet connection. The requirement of development tool is Unity3D, a game development platform.

Table 4.1:Functional requirements

No	Description
FR1	The game needs a clear instruction and UI.
FR2	User needs to register before start game.
FR3	Internet connection needs to be stable and reliable.
FR4	The game needs animations to draw attention from player.
FR5	The learning content needs to be integrated into game.
FR6	User can go back to game page after interruption by bugs or browser error.
FR7	The game needs to calculate trading profits.
FR8	The game needs audio effect to draw attention from user.
FR9	User uses navigation button to move to next location.
FR10	The user can replay the game.

4.4.3.2 System Architecture and Development

The trading game consist of five components. The ‘sign up’ and ‘Log in’ functions were implemented to verify user data. Home port and Malacca port were included in the trading system. At the end of game play, players can buy house in Malacca city and collect virtual items from physical museum setup. The virtual items can be used to decorate the house (see figure 4.9). The game was developed using Unity3D SDK. The login page requires a new user to enter basic information. When user presses log in, the game generates an account for the user. The account will store user data and souvenir data. When the player logs in to the game, he/she enters the main game.

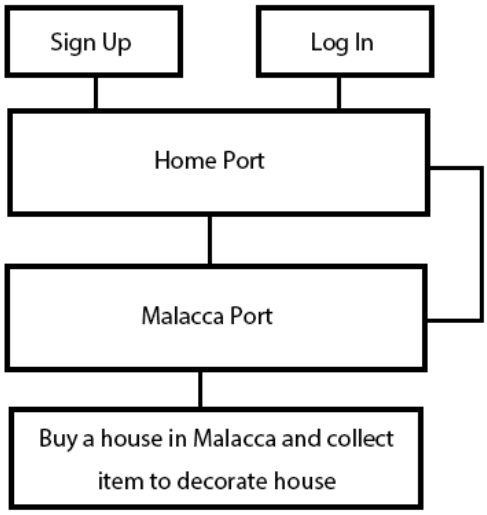


Figure 4.9:The Trading game workflow

4.4.4 Lantern Projection Mapping

A new interactive exhibit was designed to allow users to design their own lantern, a historical artefact often hung outside the homes of Peranakans to show whose house they belong as their designs would contain the owner's family name. Users could design and colour in a printed lantern, and then have it scanned and projected onto a real, physical lantern, which digital copy is also automatically stored in user's account. This exhibit was designed as such to meet the design goal of personalisation of artefact.

4.4.4.1 System Requirement

The lantern projection mapping system requirement can be divided into hardware and software requirements, and functional requirement. The following list is the minimum hardware and software requirement for lantern projection exhibit: 1) Raspberry Pi 2) Camera 3) Projector and 4) Internet connection. The requirement for development tools are Python and Laravel library. Table 4.2 shows the functional requirement of lantern projection mapping system.

Table 4.2:Functional requirement

No	Description
FR1	The user needs to enter username before they can scan their design.
FR2	The camera should easily detect images.

FR3	The system needs openCV system to process image.
FR4	The scanned digital image of lantern can be imposed on physical lantern.
FR5	The lantern image should be projected to physical lantern without delay.
FR6	The lantern image can be uploaded in short time.
FR7	User can only upload one lantern image at a time.

4.4.4.2 System Architecture and Development

Lantern projection mapping is an exhibit installation developed using computer vision and projection mapping technology. The lantern projection mapping system includes three components: log in, image processing and data processing. The login function is used to record user data and communicate with backend server. After a user logs into the system, the image processing function captures the shape of lantern on paper. The digital lantern design is then projected onto a physical hanging lantern which design can be viewed by other visitors. Simultaneously, a copy of the digital lantern is uploaded to the back-end server through data processing function to allow users to also view the digital lantern in their virtual house in the final phase of learning experience. The following figure 4.10 shows the architecture of lantern projection mapping.

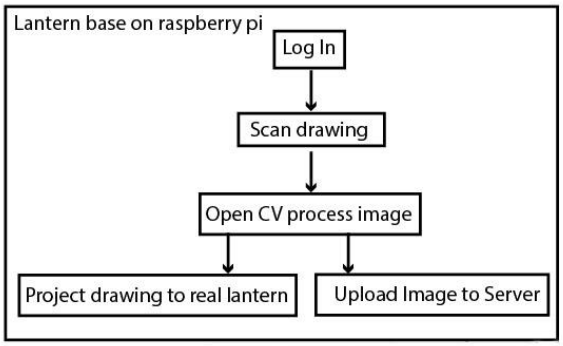


Figure 4.10:Lantern projection workflow

The following figure 4.11 shows the main function code of lantern projection mapping program. The **UserInfo** function posts the user data to back-end server. The **grablantern** function includes image processing algorithm, upload function and projection function. The development of image process algorithm is **grabcut**. The algorithm helps to grab the lantern shape from camera photo. In the end of program, it will upload image to back-end server and project the lantern image to physical lantern.

```
def main():

    UserInfo()
    grablantern(str(id))


def UserInfo():

    global id
    userinfo = {"name":"hugo","password":"unmc123456","email":"1@unmc.com","device1":"0","device2":
    r = requests.post('http://127.0.0.1:8000/api/login',userinfo)
    data = json.loads(r.text)
    id = data["id"]
    print id


def grablantern(username):
    img = cv2.imread('phototest1229.jpg')
    img = cv2.resize(img,(300,533),interpolation=cv2.INTER_CUBIC)
    rect = (40,25,250,350)


    #Grabcut algorithm
    mask = np.zeros(img.shape[:2],np.uint8)
    bgdModel = np.zeros((1,65),np.float64)
    fgdModel = np.zeros((1,65),np.float64)
    cv2.grabCut(img,mask,rect,bgdModel,fgdModel,5,cv2.GC_INIT_WITH_RECT)
    mask2 = np.where((mask==2)|(mask==0),0,1).astype('uint8')

    img = img*mask2[:,:,np.newaxis]

    #code for testing
    #cv2.imwrite('new1.png',img)
    #plt.imshow(img),plt.colorbar(),plt.show()
    #file_name = "new.png"
    #src = cv2.imread(file_name, 1)

    #save image
    tmp = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
    _,alpha = cv2.threshold(tmp,0,255,cv2.THRESH_BINARY)
    b, g, r = cv2.split(img)
    rgba = [b,g,r, alpha]
    dst = cv2.merge(rgba,4)
    cv2.imwrite(username+"lantern.png", dst)
```

Figure 4.11:Source code in python IDE

4.4.5 Virtual House Design (Post-Learning Station)

4.4.5.1 System Requirement

The following list is the minimum hardware and software requirement for virtual house design and decoration: 1) Computer support WebGL 2) Camera 3) 2 GB RAM 4) Internet connection. The requirement of development tool is Unity3D. Table 4.3 describes the functional requirement required for the virtual house design.

Table 4.3:Functional requirement

No	Description
FR1	The game needs log in function
FR2	The game needs QR code scan function
FR3	The game can download user data from server
FR4	The virtual furniture can be activated by QR code
FR5	The game needs a clear instruction
FR6	The user can upload comment when finish task
FR7	All virtual furniture must be displayed correctly in the selection bar

FR8	The user can print house design as souvenir

4.4.5.2 System Architecture and Development

The main game of virtual house design is developed by using Unity3D. The house design game has four main components: login function, furniture collection, virtual rooms and print souvenir page (see figure 4.12). The Login function allows players to return to the online trading game having entered user data. The furniture collection function can be activated by scanning QR codes collected from various interactive exhibits having completed the museum tour (see figure 4.13). The virtual furniture or item will appear according to the ones chosen or designed by the player, ready for them to decorate their virtual house with. At the end of game, they can comment on their learning experience and print out their virtual rooms as a physical souvenir to bring home.

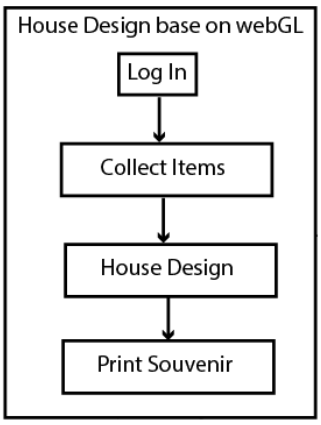


Figure 4.12:Virtual house design game workflow



Figure 4.13:Participant engagement with virtual house

4.4.6 Back-end Server

4.4.6.1 System Requirement

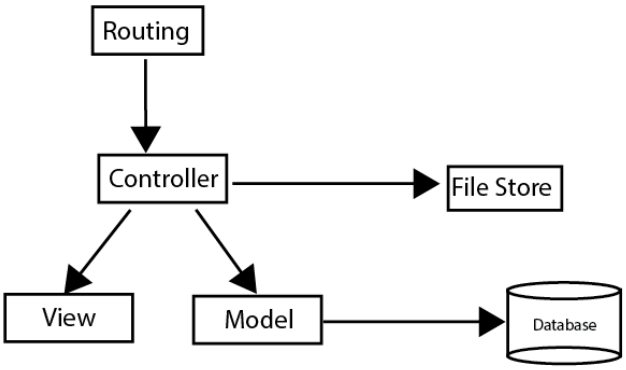
The following list is the minimum hardware and software requirement for back-end server: 1) Google Cloud APP engine and 2) Internet connection. The following list is the requirement of development tool: 1) PhP 2) Laravel Framework 3) MYSQL and 4) Google Cloud API. Table 4.4 shows the functional requirement of back-end server.

Table 4.4:Functional requirement

No	Description
FR1	The back-end server provides Restful API to exchange data
FR2	The back-end server needs FTP function for data store
FR3	The Back-end server needs a function to update data to SQL database
FR4	The Back-end server needs a function to process data from sensors
FR5	The Back-end server needs a function to access data from SQL database
FR6	The Back-end server needs a function to handle error massage

4.4.6.2 System Architecture and Development

The following figure shows back-end server architecture. The back-end-server based on Laravel MVC framework. In Laravel framework, Model components response to all the data-related logic. View components used for all UI logic. Controller components bridging Model, View and other components. The Controllers mainly handling all the business logic and incoming requests, logic computing. In this system, user request sends through Routing to Controller components. The controllers handling different types of request, such as file store, user verification. In the end of development, the back-end-server was deployed on Google Cloud App Engine Service (see figure 4.14).



Backend system base on Laravel Framework

Figure 4.14:Back-end System

4.5 Evaluation and Result

4.5.1 Experimental Setup

The evaluation was carried as part of a public exhibition at the Baba Nyonya Heritage Museum held in March 2018 involving groups comprising of families with children (see figure 4.15). The project employed surveys, interviews, user observations and video analysis as the evaluation methods. All participants filled in consent forms agreeing to participate in the study and to be video recorded. They also completed a pre-test survey to provide their demographic details (e.g., age, gender, education level). The pre- and post-test domain knowledge surveys consisted of 11 items designed to test participants' knowledge of the Baba Nyonya culture that formed the basis of the culture-related exhibits. Question items were different for the pre- and post-test instruments but tapped the same knowledge content. Learning outcomes were measured using changes in performance from pre- to post-experience. Participants' attitudes towards the exhibition experience were surveyed after the visit, employing a 7-point scale to indicate agreement with the four statements (see section 6.5.3). Video data were collected in the trading game station to support user observation. A self-guided map was provided to each group.

In addition, the measure of reflection refers to previous research (Cosley et al., 2008; Mekler et al., 2018) that employ interviews to assess levels of reflection among users. Similarly, in the study open-ended questions in survey and interviews were used with participants to determine their levels of reflection as a result of the IoT serious game

experience. According to Mekler et al. (2018), the study highlighted that participants may find it difficult to express their thoughts when interviewed with audio recorder. Therefore, the study also complemented interviews with phone interviews that were conducted 3-days post-tour to gain participants reflective thoughts on their tour experience. The main museum study aimed to evaluate the effectiveness of IoT serious game at supporting cultural learning and reflection within the context of Peranakan culture.

4.5.2 Participant Demographics and Information

The user trial involved 10 groups, with 32 participants in total. The group size ranged between 2-6 people. All participants were visitors to the museum and from Malaysia. Three groups were residents of Malacca. In the resident group, two groups had visited the museum before. The individual participant age ranged from 6 to 48 years (mean (M) = 22.19 yrs; standard deviation (SD) = 17.18 yrs). There were 19 children under age 18 (M = 10.5 yrs; SD = 2.61 yrs) and 13 adults above the age of 18 (M = 42.0 yrs; SD = 5.53 yrs).



Figure 4.15:Second User Trial

4.5.2 Learning Outcome

Post-test results on learning gains were compared with pre-test results. In the pre-test, there were ten questions to measure the existing knowledge of participants. In the post-test, it used the same question to evaluate learning effect. In the design of questions, questions were related to the history of Peranakan culture which learning content could be found in the traditional museum tour, trading game, lantern projection mapping, Batu Boh simulator and Goldsmith simulator.

A single factor analysis of variance (ANOVA) was carried out on learning items with repeated measure (pre/post). In the analysis of children group, There was a significant main effect of test ($F [1,62] = 84.5$, $p < .05$), with post-test scores being significantly higher ($m = 51.88$; standard error (se) = 4.24) than pre-test scores ($m = 93.1$; $se = 1.45$) overall. Figure 4.16 shows the learning outcomes from pre to post experience. The percentage of correct answers of adult increased from 59.2% to 93.1%. The percentage of correct answers of children increased from 46.8% to 93.12%. In conclusion, there was a significant result where learning outcomes were enhanced through the serious games learning experience involving interactions with the interactive exhibits.

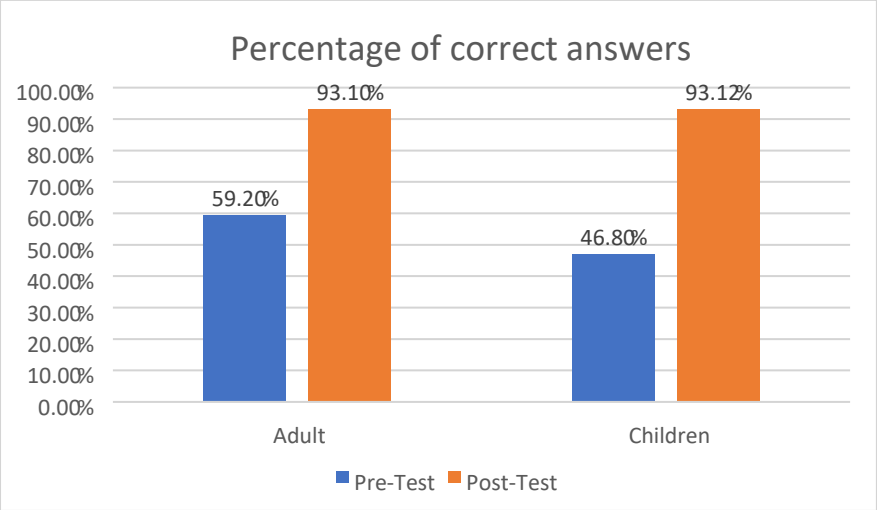


Figure 4.16:Learning outcomes from pre- to post-experience

4.5.3 User Experience Survey Feedback

The exhibitions experience implemented 7-like scale which 1 represent “Strongly Agree” and 7 represent “Strongly Disagree”. The following table 4.5 lists the agreement with statements about the visiting experience. In the exhibit experience result, a huge number of participants agreed that the IoT serious game improved their experience during the tour. The table shows the questions related to the experience where the ratings were used to calculate the mean (m) and standard deviation (sd).

Table 4.5:Statements about the experience

Question	Mean	SD	Agree rate
1. The trading game added to the enjoyment of the tour.	5.75	1.18	89.3%

2. The trading game helps me learn more about the Peranakan history.	5.68	1.07	93.4%
3. The physical interaction with interactive exhibits enhances my learning experience.	6.17	0.60	100%
4. The game creates an immersive museum experience.	6.35	0.71	96.4%

4.5.4 Open-ended Survey Feedback

The post-test survey also allowed participants to provide open-ended feedback on their user experience. In question 1 where participants were asked about which part of the experience, they enjoyed the most, about 46.67% of them felt that the Batu Boh provided them with the experience that they enjoyed the most. In question 2 which asked which part of the experience that surprised participants the most, most of them felt surprised about receiving the Batu Boh souvenir (37.5%), being able to decorate virtual house (18.75%) and seeing the lantern projection (18.75%). In question 3, participants were asked “What discussions did you have with each other during the tour? Did you share a personal story?” of which many participants reported that they talked about their own childhood memories. For example, some said they were “retelling some stories to our own children” and the experience “brought back a lot of memories”. Many participants also discussed about how things were made or done in the old days e.g. how to make *kueh* and a few discussed about the artefact as to why, how and when they were used such as “How they did things in the old-fashioned kitchen”. When participants were asked “Do you have any new understanding of Peranakan culture after the tour?”, their answers from question 4 showed that most participants learned something new or deeper about the Peranakan culture – some at descriptive reflection level e.g. as “I learned the trader’s origin and some food better”, and dialogic reflective level e.g. “Significance of bats in the Peranakan culture”. Higher levels of reflection were also reported to include transformative reflection such as “Greater understanding in diversity of country / culture origins influencing food, house and objects”, and that the culture is “very rare and very special” and critical reflection of issues such as the family dynamics e.g. “It has very harmonious family dynamic”.

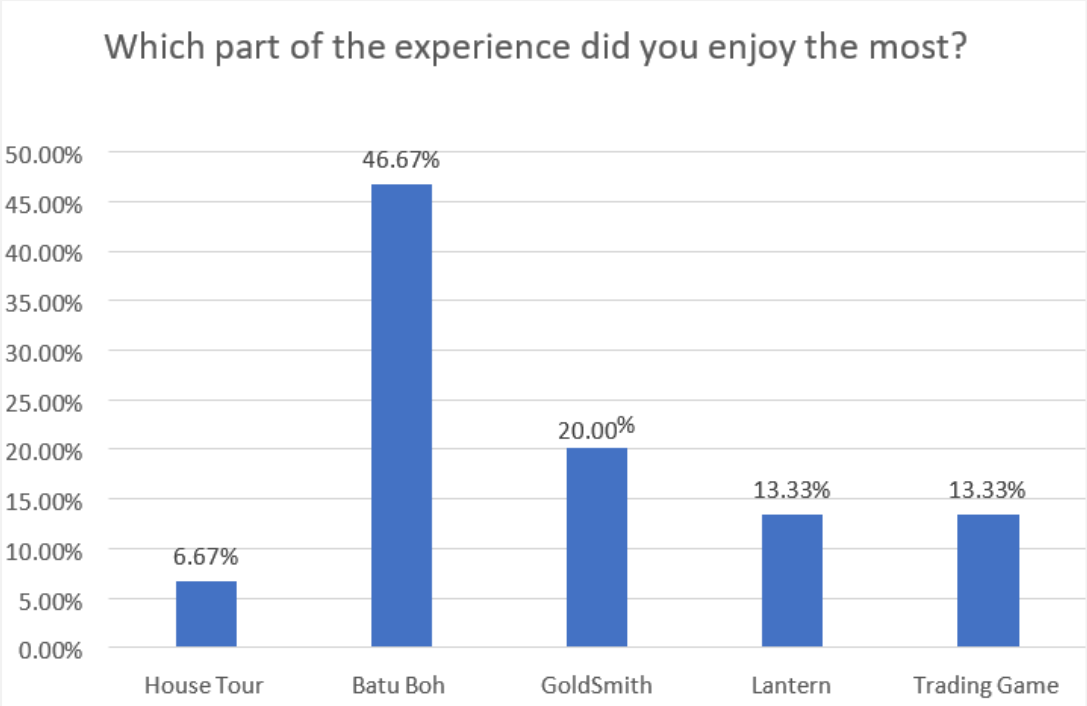


Figure 4.17 : Question 1 Result of user experience survey

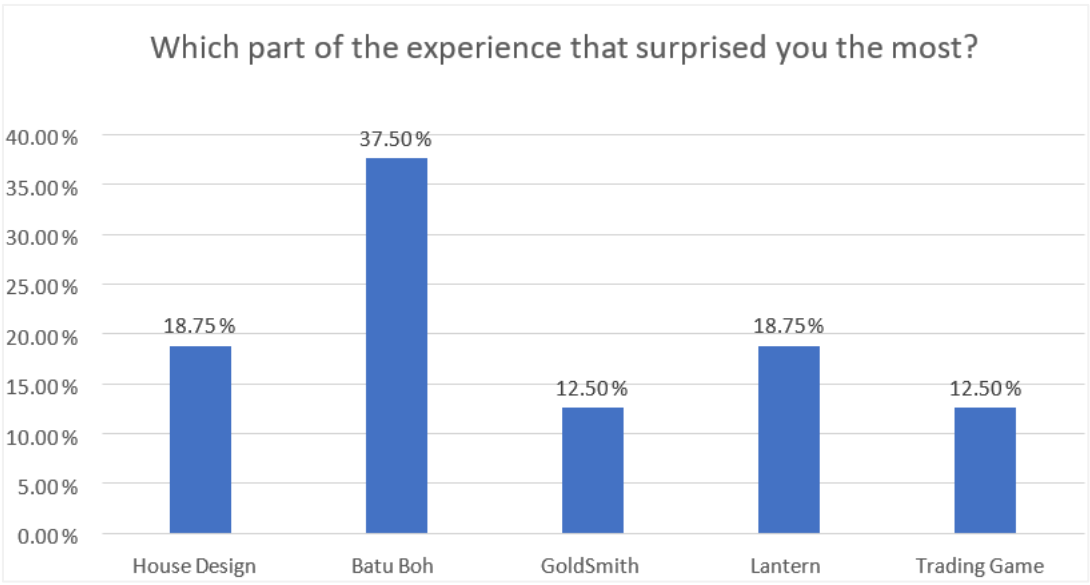


Figure 4.18:Question 2 Result of user experience survey

4.5.5 Result of Evaluation

Interviews were conducted with participants immediately upon their completion of the tour and three days later after the tour (through phone interview). The latter was

conducted to find out if they discussed anything from the museum experience post-tour and if yes, what they reflected upon. More specifically, two questions were asked: “Did you have any discussions with your family after the museum visit e.g. during meals or car rides? If yes, what did you discuss about” and “What personal thoughts did you, your child or spouse have after the museum experience?”. For the interview questions immediately after the tour, four questions were asked to family groups to find out if they have any new understanding of the Peranakan culture, how they think the culture is similar or different from theirs, how the tour changed their perspectives of Peranakan culture and if anything surprised them from the tour. Eight family groups participated in the interview immediately after the tour, while only four family groups agreed to participate in a phone interview a few days after the tour. The interviews were audio recorded, transcribed and analysed by applying the reflection framework by Fleck and Fitzgerald (2010). The interview scripts were coded and grouped based on the above thematic analysis and agreement by two researchers (author and supervisor) (see Section 6.5.5.6). User observations and video recordings were also made to study user engagements and capture discussions they had with each other while on the tour. The following sub-sections present results of evaluation on the five exhibit game stations (e.g. how successful they were at supporting user engagement, learning and reflection) and followed by a critical presentation of evidences associated to all levels of reflection as captured and analysed from the interviews.

4.5.5.1 Trading Game

Based on the initial design goal, the role of the online trading game was to provide the basis of knowledge on the origins of the culture. The results of video analysis and user observations showed that the pre-learning station was successful at providing an engaging historical story context as backdrop to their subsequent tour experience. A high level of engagement was observed between participants and the game learning content which also led to many discussions among group members. For example, participant D1 and D2 reported “*I like the trading game. Because as a computer game, it was fun to remember*” and “*My sons (ages 10 & 12) especially liked the trade game. They even asked if we could download it*”. The main discussion among group members was often on game strategy e.g. on how to win and which country to trade with. For example, a parent from group 1 guided his child to buy more items to sell saying “*You can buy more to sell from China*” and “*Wow! You get 2000 golds already. Buy more stuff in next round*”. This kind of discussion provided foundational knowledge for deeper understanding of the trading process and origin of culture. A shown in figure 4.19 involving group C, the family members were observed to discuss the game content where a child shared his trading experience with others *“Buy that one. It sells 900…Don’t buy tea. It can’t make much money”*. Overall, the trading game helped

participants to learn the basic knowledge related to the origin of the Peranakan culture such as “I learned that Malacca was one of the trading ports. And that I don't know”. It also led to deeper understanding of the culture and thus higher level of reflections as described in later section 4.5.5.6.



Figure 4.19:Participant discuss the content of trading game

4.5.5.2 Lantern Projection

At the lantern projection station, the project used computer vision and digital projection to allow participants to customise their own lantern to represent their virtual house and have it projected onto a real antique lantern. The physical task involved young participants drawing and colouring a printed lantern shape with their family name as how the lantern was used in the past. The lantern projection was designed to support personalising of artefact and physical interaction for engagement. Through survey feedback, Group A mentioned that they were surprised when they saw their own designed lantern being projected onto the old lantern and to see it in the virtual house decoration game e.g. *“At first, our son was asked to do colouring on a lantern, but it turned out projected over there. Those are surprises and then it can be printed out”.* The result showed that the process of personalising artefact through design highlighted special elements of the culture that participants may not be aware of in the traditional tour. The lantern design activity also often led to discussions among families e.g. “*We discussed what to draw in my lantern”.* The result showed that the lantern projection encouraged discussions on cultural elements. Additionally, the evaluation also observed participants were interested in their personalised lantern. For example, as shown in figure 4.20, two young participants were surprised to see their digitally augmented lanterns and took photos of them.



Figure 4.20:participants feel surprised by lantern projection and take photo

4.5.5.3 Goldsmith Simulator

The design iteration was carried out on the goldsmith simulator based on the pilot study to improve its performance in detecting gestures and decreasing the level of difficulty in jewellery making for young participants. The station allowed participants to learn the process of jewellery making as a goldsmith, allowing them to learn how to solder a jewellery pendant or '*keronsang*' using tools such as a virtual 'daching' for measuring weight and a physical 'bellow' for pumping air. The participants were given a task of making a virtual jewellery through physical and digital interactions to learn other cultural influence that exist in the Peranakan jewellery e.g. participants could choose a British silver coin to combine with a Chitty pendant frame. One participant learned about the measurement tool by goldsmith and feedback that it was a new experience. The result of video analysis and user observations showed that participants enjoyed engaging in the jewellery making activity (see Figure 4.21). For example, participant C1 mentioned: "*Well. I just like the goldsmith virtual reality. I didn't expect that at all. Um, so I think it's kind of a fun video game for the kids to do something interactive. Um, and I think it does make it more alive than just looking at some piece of jewellery".* There were also instances where participants were surprised by the interactivity e.g. "*I think the computer stuff surprised me. Like you know. you can make brooches ..using your hand*" (A2).



Figure 4.21:Participants making virtual jewellery

4.5.5.4 Batu Boh Simulator

A design iteration was carried to improve the delivery of learning content through the Batu Boh simulator based on the pilot study. Having to separate and interweave listening of audio narration (e.g. of chef talking) and physical 'grinding' activity helped participants in concentrating in listening to the historical learning content provided through conversations with the 'chef' in contrast with pilot study. In the IoT serious game design, the Batu Boh simulator played a role in supporting physical interaction to encourage more visitor engagement, learning and reflection. Many participants remarked that they learned to make a *kueh* from the station e.g. "*I learned to make kueh*" and "*I knew what ingredients needed when making a kueh*" as examples of descriptive reflective. There were also evidence of higher level of reflections for example when a participant shared how the interactions helped him become more aware of how different food came from all throughout the world and mixed together in a very amazing way. where e.g. this time I became even more aware that different things in the house different food, different decorations all come from all throughout the world and it's all mixed together in a very amazing way. And today's interactions help me become more aware of that." The dispensed capsule containing the '*kueh*' that participants made were found to be a surprising element in the museum game experience. The result of evaluation showed that the Batu Boh simulator played an important role in supporting learning and building foundation understanding for deeper reflection. More evidences of deeper reflection are discussed in section 6.5.5.6 below.



Figure 4.22:Participants explored different recipes to collect different souvenirs (Top) Participants discussed about the real Batu Boh after interacting with the Batu Boh simulator (bottom)

4.5.5.5 House Decoration

The virtual house decoration station provided a chance for participants to convert their collected items from the physical tour to the virtual world. The game included a virtual house decoration feature and a comment system for participants to share thoughts. The house decoration station provided participants with a chance for participants to review collected artefact and discuss about the souvenirs. As shown in figure 4.23, when a participant logged in to his virtual house, he felt surprised and exclaimed: *"Wow! My lantern is here"* and another child said: *"Where can you put the lantern? Can I have my one in here?"* The result of evaluation showed a little, though much less compared to all other stations, evidence of discussion among group members. There was one instance where a participant thought of "How did the Peranakans utilise each section of the house". However, the evaluation result found that the participants were shy to share their thoughts on the comment function except for one child participant only.



Figure 4.23:Participants decorating the virtual house

4.5.5.6 Level of Reflection

Level 1 Reflective Description: According to Fleck and Fitzpatrick (2010), to achieve the lowest level of reflection, the game design needs to encourage some form of reasoning of knowledge, but with no exploration of alternate knowledge. The project expected the lowest level of reflection as the most common categories where participants expressed some understanding on the cultural elements and/or history of the Peranakan culture without providing further explanation or evidence of reflective thought. Result of the main museum study showed many examples of participants engaging in Level 1 reflection, which was important to help participants gain basic understanding of the culture in order to improve their learning gains. For example, D1 remarked *"I think it's really, really effective at making it fun. and getting most people at least a basic idea of culture"* and similarly A2 shared" *It definitely enriched my understanding of little things here and there, like the trading game*". The gamification elements across all game stations seemed successful at helping them learn about the culture as supported by feedback from participant E1 "*I think the interactive program helps to enhance the learning experience*" and another "*The tour is creative, enjoyable & informative*". Different cultural elements that participants came to understand varied to include the tradition (e.g. "*We noted the tradition associated with the artefact*"), food (e.g. *"I knew what ingredients are needed when making a kueh"), tools (e.g. "The measurement tool by goldsmith")* and origin of culture from trading (e.g. "*"I understand the trader's origins and some food further").*

Participants from group B mentioned that the trading game helped them learn the historical origin of Peranakan culture: *"I think I found out Malacca was a trading port"* (B2) and another participant also answered: *"Um, well, certainly there are, you know, rituals*

and traditions in different cultures" (B1). The reflective descriptions were observed as participants engaged with the game learning content and through physical and digital interactions across all stations. The above provided evidences showing how IoT serious game can encourage visitor engagement and learning e.g. as reported by B1 "*Everyone in my family enjoyed our museum visit. It does a great job of capturing a slice of Malaysian history and presents it in an interesting, hands-on way*".

Level 2. Dialogic reflection: According to the reflection framework by Fleck and Fitzpatrick (2010), dialogic reflection explores relationship between instances of experience or knowledge, consideration of different explanations and perspectives, as well as cycles of questioning, hypothesising and interpreting. In this research, it expected participants to see things through different perspectives and reach a different level of understanding on the relationship between past history and present culture, the Peranakan culture and their own culture, the different cultural elements that influenced the Peranakan culture and museum setup.

The Batu Boh station supported physical interaction to encourage dialogic reflection. Participants from group R discussed their own childhood experiences with the Batu Boh as a result of the physical interaction: *"The Batu Boh…because our grandmother's house has same one…but this one is smaller. Our one is bigger. She used it to grind soya bean…and we put different ingredients inside."* Other feedback also connected the museum experience to their own childhood experiences such as *"How did they utilize each section of the house. We used to have a courtyard in our old house last time and it brought back a lot of memories."* and *"Remind of our own childhood stories and retelling some stories to our own children"*. The participants were able to explore the relationship between the culture and their personal experiences.

In addition, more evidences were observed from the online trading game station. There were many instances where participants analysed the relationship between the culture and its historical origin such as *"I think that was good to show the different influences because they were trading between India and China and Malay and back to the UK."* (C1). In the open-ended interview, participants from group E analysed the relationship between past and present: *"So like example the peephole today, we use cctv whereas those days they just used a hole in the floor."* (B1) Some participants also came to realise the similarity between the Peranakan culture and their cultures. For example, group F gave feedback, *"Language. I am Chitty, so we speak the same language with Baba Nyonya and our food also kind of same." while* A1 shared, *"Similarities will be the emphasis on relationships. The emphasis on the filial piety and yeah, I think it's deeply*

embedded about how relationships and honouring the ancestors and your parents and children are all very important". In addition, participants also found some special relationships between different cultural elements. For example, participant A2 noted, *"So I think symbolisms are very important both in Peranakan culture and China culture. I didn't know like the three main animals. You know the crane, the bats and the deer, they are very, very, very important".* There were many examples of participants showing deeper understanding of the Peranakan culture as demonstrated by E1's explanation of the culture, *"Especially the Peranakan are a mix of the Chinese traders who came from China and the locals here. So, during that time as I saw the trading game has a port in China. Yeah. So, the traders came to Malacca and then they settled down here and they got married with the locals. So, we can see that there's elements that are similar, but then there's a lot of differences too".*

Level 3. Transformative Reflection: Based on the reflection framework by Fleck and Fitzgerald (2010), the definition of transformative reflection means revisiting an event or knowledge leading to a change in practice or understanding. The project expected participants to have a change in the belief or understanding of the Peranakan culture such as cultural similarities and appreciate cultural differences through the IoT serious game experience.

From the result of evaluation, participant G1 noted how her daughter achieved transformative learning from the trading game: *"I was surprised to hear my daughter starting to use the word "trade" in her daily conversation to initiate a trade of objects with her sister. She must have understood and internalised the concept."* Participants from group A mentioned that they learned new historical facts from the tour: *"Um, uh, yeah, I mean, I didn't know that the spice trade was actually the number one trade here. I think I had always been confused about the different place. And this was helpful. I mean at least I know a little bit about the ingredients, and I can see them compared."* Participant D1 explained what he came to know about how the Peranakan culture grew: *"Exactly how they came together. And um, is this a bit more about? I know there's a mixing of people."*. During the interview, participants from group A discussed the trading business where A1 said, *"But you can actually make money out from it and it appreciated by quite a bit like fifty percent by just moving let's say the silk, by moving from China to Malacca."* Then, participant A2 analysed the reason behind high profit margins from trading: *"Last time very dangerous. So, they can charge a lot more. So, when you just move things around us.*" Another group of participants D also mentioned that their daughters (aged 6 and 8) "Talked a lot about the kitchen*: the setup, the contents, and especially the kueh maker". D1 explained "I think this resonates with something they really like to do –*

pretend play". This showed that the activity helped participants remember more details of the tour and provided a chance for higher level of reflections.

In addition, IoT serious game provides different learning and interaction experience to participants. Several evidences showed participant become more aware of the culture. Participant A2 mentioned that *"This time I became even more aware that different things in the house, different food, different decorations all come from all throughout the world and it's all mixed together in a very amazing way. And today's interactions help me become more aware of that.".* Participant also mentioned that the tour made them realised that the Peranakan culture is a rare culture. "*Yes, I realize that Peranakan culture is very rare.* Participant group B mentioned that *". It does a great job of capturing a slice of Malaysian history & presents it in an interesting, hands-on way."* The participant started to realise that the Baba Nyonya culture is a special part of Malaysian culture.

Level 4 Critical Reflection: Critical reflection is the highest level of reflection by Fleck and Fitzpatrick (2010)**,** as it considers a wider picture where social and ethical issues are taken into consideration. To achieve this highest-level of reflection, the project expected participants to have a new view of culture and relate it to wider societal issues.

In contrast to previous study (Mekler, et al., 2008), the main museum experience having adopted the IoT serious game showed some evidence of critical reflection, though much less when compared to other levels. The IoT serious game helped participants to think in wider picture. For example, participants from group D engaged in imagination that extended from culture: *"For the peephole we imagined (jokingly) what we would do with a similar peephole in our house" (D1).* Participant A2 shared that the trading game prompted them to think widely about implications of trading business: *"We also talked about why it is important to make profits in business and also ways to do business. Sometimes business can barter trade -- no money is exchanged".* The comment from survey questions showed participants started to think more about the meaning behind culture. For example, one participant commented: *'It's not just the Chinese or the Indian or local Malays."* and another participant expressed his/her thought about the Peranakan family. *"Yes, very harmonious family dynamic."*

4.6 Conclusions

Extending from the results of pilot project, an IoT serious games had been designed to encourage meaningful and deeper cultural reflections during museum tour. The contribution of the main museum study was to address one of the research questions

on ‘How can a serious game be designed to create deeper learning engagement and reflection using IoT-enabled physical environments?’. The second phase research created a proof of concept on IoT serious game in museums which was studied in a main museum trial.

The game consisted of an online trading game and IoT based interactive exhibits. The IoT serious game bridged the physical exhibits with virtual game through game elements and IoT technology. The main museum study design showed how an IoT serious game can be developed to enhance museum experience. The design experience translated as guidelines to help future IoT serious game design. Most participants formed new understanding of the Peranakan culture through the museum tour as shown by the result of the learning gain. The IoT serious game provided an immersive experience for visitors by providing role-play game experience which showed considerably high level of success in engaging visitors and supporting different levels of reflection. At the same time, some challenges of implementing IoT serious games had been identified with the main issues that lie in difficulty with IoT game ideation and establishing communication between IoT sensors and virtual game. As such the next phase of research involved the development of an IoT toolkit for future museum innovation.

Chapter 5. IoT Toolkit Design and Development

5.1 Project Goal and Objectives

The increasing deployments of IoT technologies create new opportunities for game design for museums. Exhibit designers need to understand how to use museums and their rich collections as a game space as well as interaction possibilities that IoT technologies offer. Designing a museum visitor experience becomes a challenging process, especially if the design team intends to incorporate new technological elements and game mechanics in its design approaches. A museum curator may have limited knowledge on, for example, game design and IoT, while a developer may not have experience of curating museum content and artefacts. A museum design team comprises experts including museum curators, educational experts, visitor representatives, volunteers, and designers and developers of various multidisciplinary backgrounds, with a wide variety of perspectives and stakes. As such, the concept and development phase may take a long time in order for the group to establish the main message, themes and learning goals and have a clear understanding of different factors affecting user experience as well as user engagement possibilities. There is also a lack of IoT game development platforms to allow data communication between IoT sensors and game platform. Therefore, the project goal is to help future designers generate engaging IoT serious games in museum settings quickly and effectively. The project introduced an IoT toolkit consisting of a card game solution that synthesises design knowledge for IoT serious games in museums based on lessons learned from the main museum study and an IoT development kit that provides IoT plugins and cloud server for use with a popular game development platform, Unity3D.

The IoT card game was introduced with the following objectives: 1) to improve idea generation efficiency of museum curators and game designers, 2) to help non-experts understand IoT technology and game design, and 3) to improve visitor engagement with valuable museum content and artefacts. The IoT development kit was introduced with the following objectives: 1) to create data communication between IoT devices (e.g. board, sensors and actuators) and game development platform 2) to support data sharing among components using a cloud server.

5.2 IoT Card Game for Game Ideation

5.2.1 Design Consideration

Although much effort has been devoted to the museum experience development process, there is still much work to be done. Building on the museum study experience, the project proposed an IoT serious game card-based ideation tool to help museum curators and developers achieve high brainstorming efficiency and productivity. The tool aimed to help teams of designers acquire understanding of domain-specific design knowledge and support initial and more in-depth development of ideas by designing for deeper levels of engagement. To summarise, the project identified the following characteristics for the card game: (i) describe domain-specific design knowledge to non-experts (ii) help identify museum theme and/or learning content (iii) foster collaboration between multidisciplinary teams of designers (iv) support initial generation of ideas (v) encourage in-depth development of ideas to consider different levels of engagement. The target users for the card game will be museum curators and designers.

5.2.2 Design of Ideation Cards

The IoT card game was developed in two design iterations. The initial design of the toolkit was evaluated in a pilot study involving a class of Year 2 undergraduate students enrolled in the Human-Computer Interaction (HCI) module. The contents of the cards and game rules have been refined according to feedback gathered during formative evaluations with HCI students. The final version of tool was evaluated in a design workshop open to undergraduate students majoring in Computer Science. In this section, the project describes both version of toolkits and their evaluations to include the rationale behind the creation of the different decks of cards and the game rule.

5.2.2.1 First Iteration of Cards

The first version of card game consisted of 70 cards, each of 9 cm x 7 cm in dimension. There were five types of cards in the deck (see figure 5.1): 1) The Asset card for identifying museum content, which included a sub-level Collection card for identifying possible museum items, 2) The Engagement card for identifying the purpose of game, 3) The Serious Game card for identifying game elements, 4) The IoT card for implementing IoT sensors and actuators to enhance the game experience, and 5) The Possible Issue card for identifying possible issues in the generated game idea. The

project used color-coding based on these categories to make the cards visually more distinct.



Figure 5.1:First iteration card game

The front of each card provided a label to identify the type of card, while on the other side consisted of a label for type of card, an associated symbol icon and a suggested component for design considerations.

5.2.2.2 Final Deck of Cards

Asset card: The Asset card helps teams of designers identify the focus of the museum visitor experience. The Asset cards are subcategorized into three sub-types, namely Culture opportunity, Location opportunity and Visitor opportunity. The sub-level cards help design team to analysis museum asset. During the brainstorming session, the Culture opportunity helps participants identify valuable museum collection through themes such as Music, Artwork, History, Customs and Traditions, Performance Art, Religion, Food, Artefact, Clothing, Religion, Recreation, Architectural design, Economic System, Social Organisation and Language. The location opportunity card helps participants explore various spaces and/or locations in the museum that could be used.



Figure 5.2:Second iteration Card Game

The visitor opportunity helps participants identify a target visitor group in which the IoT game experience is to be designed and catered for - it could be Family, School Children, Local Community, Young Adults and Tourist groups. Since the success of the visitor experience rests on how well it meets the needs of targeted user group, decisions on designs should be closely tailored to the specific need of the group. For example, when designing apps and games for school children, designs should display clear, specific instructions, leveraging kids' mental models and prior knowledge; keeping in mind that their cognitive ability is still developing.

Engagement Card: As museums deal with a multitude of unique challenges today, visitor engagement is becoming more crucial than ever before. Museums have the desire to be socially relevant in a changing cultural field. The key to this is to engage with audiences at a personal level and to deliver high quality visitor experiences. Real engagement is only significant once a two-way dialogue is established between the museum and its audience. The Engagement card encourages designers to consider different aspects as well as levels of engagement so that museums can think very carefully about the way they wish to attract as well as impact their audiences. Different aspects of visitor engagement opportunity to consider in the card game range from improving learning gains to social bonding, while deeper levels of engagement may be incorporated into the design idea through the following Engagement cards: Relationship Reflection, Transformative Reflection and Critical Reflection, building on the different possible levels of reflection (Fleck and Fitzpatrick, 2010). The Engagement card introduces participants to possible engagement goals and encourages them to support real engagement in the game experience.

Serious Game Card: Serious games are commonly defined as games that have explicit and carefully thought out educational purpose and are not intended to be played primarily

for entertainment (Michael and Chen, 2005). A serious game needs to combine a number of different aspects in the design, stemming from different fields of expertise. For museum curators, designers, developers and other stakeholders, it can be challenging to organize the design process to make sure that these aspects are properly addressed. Hence, the research project have identified three aspects that influence the design of serious games and incorporated them into the Serious Game cards: 1) Gameplay opportunity cards describe types of games that are commonly designed for museums to include Treasure Hunt, Riddles, Role Play, Story Narrative, Creativity, Collecting, Physical Action, Collaborative and Mini Game, 2) Game element cards describe tools and rules that define the context of game play to include Point System, Ranking System, Souvenir and Headquarter and 3) Game platform cards describe possible technological platform that the game experience could be built upon to include Mobile App, Interactive Artefact, Augmented Reality and Virtual Reality. The Serious Game cards help identify which game activities are best suited to help visitors achieve the intended engagement outcomes.

IoT Card: IoT is widely accepted as an intersection of people, systems and physical world (Ghajargar, Wiberg and Stolerman, 2018). In the card game play, the project maintain the assumption that there is presence of a network infrastructure or network connectivity in museums, which allows the interoperability of the elements of an IoT. The focus of the IoT cards is to highlight sensors and actuators that could be embedded into physical objects to enable visitor engagement with museum artefacts or environment. The IoT cards encourage participants to pay particular attention to the design of effective interfaces that will engage visitors in a high quality experience. For example, in order to support reflective thinking, the design of sensory and physical characteristics of the artefact itself play crucial roles. When a user interacts with an artefact, the artefact provides feedback, creating loops of actions and feedback that can shape and personalise the interaction (Dietrich and Van, 2014). This level of interaction with smart artefacts enabled by IoT, supports openness to interpretation, experimentation and exploration which are all important drivers of reflection. The IoT card introduces IoT technology to non-technical participants. The IoT card is grouped into IoT Input and IoT Output cards. The IoT Input cards describes different types of input sensors to include Touch Sensor, Tilt Sensor, Fire Sensor, Soil Sensor, RFID, IR Sensor, Colour Sensor, Button, Temperature Sensor, Motion Sensor, while the IoT Output cards describes different types of actuators to include Motor, LED, Digital Graphic, Animation, Video, Smart Switch. The IoT card provides a chance for participants to extend their game idea to bridge virtual world and physical world and enhance the game experience with physical interactions in order to achieve high visitor engagement.

Possible Issue card: The possible issue card helps participants identify potential risk in their brainstormed design ideas. There are 16 Possible Issue cards in the final card

version categorized according to Technology, Player, Location and Reflection challenges, to include Battery Life, Networking Connection, Loud Noise, Confusing Instruction, Accident, Intergeneration Gap, Lighting, Communication, Physical Artefact, Information, Reflection Time, Past and Present Connection, Cultural Differences, Cultural Content. For an example, to solve the possible issue of Intergeneration Gap, participants will need to think of solutions as to how the game can engage both older and younger players. In summary, the Possible Issue card helps participants think more deeply to refine their brainstormed ideas and create better visitor experiences.

5.2.3 Evaluation Result

5.2.3.1 Pilot User Study

5.2.3.1.1 Method

The pilot user trial involved 25 Year 2 undergraduate students who enrolled in the Human Computer Interaction (HCI) module. The IoT Serious Game card was used by participants as part of a HCI Design Challenge. Participants worked in groups of five. In total, there were 5 groups, resulting in five different design ideas being generated through the card game session. Prior to the card game session, participants carried out an ethnography field study which allowed them to gain experience in integrating the theoretical perspectives of interaction design learned in the classroom with experiences gained in the field. Through the study, participants were able to understand the context of design, identify problem areas for improvement and interpret the data gathered to determine design implications. The IoT Serious Game Card was then used in an hour-long workshop to generate ideas for a new interactive experience to improve the visitor learning experience at the science museum. After the ideas were finalised, each group presented their outcomes in a short presentation to a panel of judges. After the card game session, all participants completed a post-test survey (Appendix D) to rate the quality of the process, different types of cards and brainstormed ideas in a five-point Likert scale.

5.2.3.1.2 Rule of Cards

In the pilot study, the first iteration of the rules of the card game consisted of a five-step process based on random draw as below (Each step takes 5 to 10 minutes, when designers feel content is enough for brainstorming, the game move to next step.):

1) Designers reveal three random *Asset cards* and two random Collection cards. The cards help identify the domain focus of the game based on the different categories (e.g. artifact, history, story) as suggested by the drawn cards. They are allowed to remove any cards that may not be relevant to their ideas at any point in the game. Designers are encouraged to write down their game ideas.

2) Designers reveal two random *Engagement cards*. The cards help designers develop a storyboard that will enrich visitor engagement by encouraging designers to consider ways to create engaging experiences (e.g. immersive and fun).

3) Designers reveal three random *Serious Game* cards. They can define a game genre and incorporate game elements into the developed ideas.

4) Designers reveal three random *IoT* cards. They then jointly discuss how the IoT elements can be combined with game elements into one game idea. When they feel they have covered the important aspects, they move to final step.

5) Designers present their IoT serious game idea to other groups. Other groups can draw a *Possible Issue* card to challenge the idea. The cards help evaluate if there are any flaws in the design.

5.2.3.1.3 Example of Generated Ideas

The following provides examples of IoT serious game ideas generated by the HCI student groups, which were further prototyped as shown in figure 5.3:

- Interactive exhibit A consisted of a rotatable tube of different gases to allow users to observe the light spectrums of gases that exist in space through spectroscopy. Users learn about each gas from a digital display and answer quizzes by pressing a button (see figure 5.3(a)).
- Interactive exhibit B allowed users to explore a 3D virtual space environment using navigation buttons and engage users in mini-quizzes as users encounter different type of gases in space (see figure 5.3(b)).
- Interactive exhibit C was a Drag and Downforce Game Simulator which used a mini physical model of a F1 car to provide simulation of drag and downforce using water vapour and to show changes when users physically move the flaps to help users learn about aerodynamics of an F1 car (see figure 5.3(c)).
- Interactive exhibit D was designed as simulation game that encouraged users to turn a physical wheel to pump oil into a tunnel to learn about how an oil platform

works. An IR sensor was used to count the number of wheel turn which would in turn control the oil flow (see figure 5.3(d)).



Figure 5.3:IoT serious game ideas generated and prototyped

5.2.3.2 Second User Study

5.2.3.2.1 Method

Based on results of initial user study, the research project re-designed the game cards to provide clearer descriptions for all cards and increased the number of cards from 70 to 90. The second user study involved 19 participants, who were Year 1 and 3 undergraduate students majoring in Computer Science. The participants were divided into five groups, each consisting of 3 to 4 participants. To begin with, participants were given the task of designing a museum experience for a local cultural heritage museum. Each group was provided a self-tour guide book of the museum and given 15 minutes to learn and understand about the cultural heritage including artefact and places situated in the museum.

Then they followed the rules of the game card to generate IoT serious game ideas suited for the context of the museum. The finalised ideas were written down on paper and presented to other groups (see Fig. 4). The card game play was held in an hour-long workshop session. After the card game session, all participants completed a post-test survey and participated in a group interview to feedback on the card game and their game play experience.

5.2.3.2.2 Rule of Cards

The rules of the card game were slightly revised based on the results of evaluation from the first user study. Each participant draws a card in turn and share his/her idea. Similarly, participants were allowed to remove any cards that may not be relevant to their ideas at any point in the game. Each step takes 5 to 10 minutes, when designers feel content is

enough for brainstorming, the game move to next step. Designers were encouraged to write down their game ideas. Since sub-level cards of Collection were removed, and merged into *Asset* cards, participants only needed to draw cards from *Asset* as below:

1. Designers reveal three random *Asset* cards.
2. Designers reveal three random *Engagement* cards.
3. Designers reveal three random *Serious Game* cards.
4. Designers reveal three random *IoT* cards.
5. Designers reveal three random *Possible Issue* cards to challenge the idea.

5.2.3.2.3 Example of Generated Ideas

All of the groups successfully generated IoT serious game ideas within a short time frame of an hour. The following describes the final game ideas generated by participants:
- A mobile treasure hunt application encourages users to solve riddles and explore the museum. The mobile game implements sensor technology to let users receive riddles when they get near to '*special*' artefact. The game implements a point system with a ranking board to show the players' points.



Figure 5.4:Game play and generated ideas written and presented by participants

- A mobile puzzle game allows users to collect Augmented Reality (AR) markers to unlock a puzzle which in turn reveal a virtual artefact. The virtual artefact is associated with an augmented physical artefact, embedded with a button, touch sensor and IR sensor. Users can play and interact with the interactive artefact

and gain points. At the end of the tour, visitors can exchange the collected virtual artefact with a souvenir gift.

- A mixed reality game allows users to wear a pair of mixed reality smart glasses (e.g. Microsoft HoloLens) to explore augmented artefact in the museum. When users interact with the interactive artefact, it will trigger virtual effects which can be viewed through the smart glasses.
- A VR role play game allows users to experience a cultural story and then solve riddles by interacting with IoT sensors embedded in the physical environment to unlock tasks.
- A VR game encourages users to explore and find tagged objects e.g broken pieces of plates in the physical environment to unlock virtual information on the history and cultural significance of the objects.

5.2.3.3 Comparison result between two cards

A questionnaire was administered right after the card game workshops in both studies. The questionnaire used a 5-point Likert scale, ranging from “Strongly Disagree” (assigned value to one) to “Strongly Agree” (assigned value to five). Data from the questionnaires was analysed using SPSS software, where the ratings were used to calculate the mean (m) and standard deviation (sd) for each question in both studies as shown in Table 5.1. The questionnaire was completed by 44 participants in total; 25 participants from the first user study and 19 participants from the second user study. The participants’ amount of experience in game development varied across all levels from low to high (m = 2.88; sd = 1.09 in first study and m = 3.21; sd = 0.97 in second study). The questionnaire included questions about acceptance and usefulness of the tool. It also explicitly asked the participants if using the card game was helpful in their brainstorming and game idea development process. The goal of the second user study was to determine if the changes made to the cards improve the playability and effectiveness of the card game as an aid to idea generation and development.

Data from the questionnaires produced in Table 5.1 suggests that the card game workshops were well accepted among participants. More than 76% and 79% of the participants from the first user study (m = 3.76; sd = 0.87) and second user study (m = 3.89; sd = 0.74) considered IoT serious game card fun. The percentage of participants who agreed that the card game was enjoyable to use increased from 68% to 83% in the

second user study (m = 3.68; sd = 0.9 in first study and m = 3.89; sd = 0.66 in second study).

Table 5.1:Results of card game survey

Question	1st trial		2nd trial	
	m	sd	m	sd
Q1. Before the workshop, I had the following amount of experience developing games	2.88	1.09	3.21	0.97
Q2. The cards were very helpful for brainstorming.	3.8	0.5	4.05	0.7
Q3. The cards were easy to understand.	3.2	1.08	3.52	1.22
Q4. It was fun working with the cards.	3.76	0.87	3.89	0.74
Q5. I enjoyed using the cards.	3.68	0.9	3.89	0.66
Q6. The game method was very helpful for game design.	3.56	0.77	3.95	0.71
Q7. The card game helped me learn about the game design process.	3.64	0.81	3.74	0.85
Q8. The card game helped me learn about IoT technology.	3.42	0.77	3.1	0.99
Q9. The card game challenged me to think 'out of the box'.	3.88	0.97	3.94	0.62
Q10. The card game was very useful to help me design for reflection.	3.48	0.82	3.78	0.63
Q11. I am very satisfied with the quality of the brainstormed idea.	3.6	0.71	3.47	0.77
Q12. The number of cards is enough for me to brainstorm.	3.48	0.91	3.84	0.89
Q13. The Engagement cards were very useful for brainstorming.	3.48	0.91	3.84	0.69
Q14. The Technology cards were very useful for brainstorming.	3.83	0.92	4	0.66
Q15. The Asset cards were very useful for brainstorming.	3.16	1.02	3.32	1.1
Q16. The Challenge cards led to productive discussions in the group.	3.64	1.15	3.95	0.78
Q17. The Possible Issue card helped me identify problems I would not have thought of.	3.6	1.11	4	0.94

In addition, more than 72% from the first user study (m = 3.8; sd = 0.5) and 89.5% of the participants from the second user study (m = 4.05; sd = 0.7) considered the card game very helpful for brainstorming. The card game was able to challenge them to think creatively, ‘out of the box’ (m = 3.88; sd = 0.97 in first study and m = 3.94; sd = 0.62 in

second study) and provided enough guidance to help them learn the game design process (m = 3.64; sd = 0.81 in first study and m = 3.74; sd = 0.85 in second study). The result of questionnaire from the second study showed a more positive outcome regarding almost all aspects of the card game after its revision based on feedback from the first user study. The result of the questionnaire and interviews from the first user study revealed that the IoT and Asset card description were unclear and the concept of sub-level cards such as the Collection card being part of the Asset card was hard to understand. Based on the feedback, the research project improved the card game and generated a second version card game, resulting in higher acceptance of IoT card (m = 3.83; sd = 0.92 in first study and m = 4.0; sd = 0.66 in second study) and Asset card (m = 3.16; sd = 1.02 in first study and m = 3.32; sd = 1.1 in second study).

A question featured in the interview: Do you feel the IoT card help you understand IoT technology? yielded positive answers among groups such as "*I think it can actually help those people who have no prior knowledge about IoT because it's quite simple and it's easy to understand. Yeah, so you don't have to have any existing knowledge of IoT in order to use the card."* and "*Yes, with the help of this card, we are able to know different possible IoT technologies. And with that we can integrate different IoT technology to help create the application".* When participants were asked if the card game helped them to identify museum theme and learning content better, group C agreed that, "*I think it helps because it helps give direction to where you want to go. So, for example, if you get Culture cards, you'll be focused on the culture instead of just making".* In addition, to the question: Do you feel the card game encouraged you to do more discussion? Group D replied "*I think it's a very good way to brainstorm because it opens up some avenues that I've never actually thought about. And sometimes when you're brainstorming, you get stuck on a single idea but with different cards help you expand".*

5.3 IoT Development Kit

5.3.1 Design Consideration

There are many software and hardware development kits that have been developed for the rapid development of IoT systems (see Section 3.1 and 3.2). During the development of the IoT serious game, the project found that the development involving connecting hardware devices with software development platform would be a big challenge for software developers. The hardware development board communication with the software platform is mainly dependant on either bluetooth or Wifi for establishing internet connection. The setup and development of communication between devices using Wifi

normally takes a long time, while the bluetooth solution is comparatively easier and involves lesser setup time. However, the connection with Bluetooth solution is not as stable as Wifi and the range of communication distance between devices that it can support is limited. Therefore, the project introduced an IoT development Kit based on Wifi to fill the communication gap between the hardware development kit and game development platform.

Initial research on the design of IoT development kit involved investigation into existing IoT toolkit solutions. RapIoT is one of IoT toolkits that is designed to help in rapid IoT system development. However, its weakness is in its high latency on communication. For the purpose of game development, the project will require low latency on data exchange. For the hardware implementation of the project, the IoT development kit implemented Raspberry Pi as the development board. Compared with other solutions such as RapIoT that implements Arduino as development board, Raspberry Pi provides a more powerful computing development platform Arduino. In addition, Arduino does not support internet connection where the data exchange will need to use a mobile phone as router to connect the server with Arduino. On the other hand, Raspberry Pi comes with internet function. Finally, RapIoT is difficult to setup due to unclear instructions.

In summary, there are two design considerations in the implementation of the IoT development kit: 1) The communication system of IoT development Kit needs low latency. 2) The IoT development kit needs a clear instruction for easy setup.

5.3.2 System Analysis and Design

This section details the system analysis and design of the IoT development kit. The system analysis process helped identify the functional requirements of the kit. The system requirement of the kit was generated from the project's museum studies. The system architecture describes the main components of IoT development kit to include the back-end-server, Unity3d plugin and Raspberry Pi plugin. The following section describes the system requirements, user case diagram and activity diagram.

5.3.2.1 System Requirement

The system requirement can be divided into hardware and software requirement, and functional requirement. The technical requirement lists the minimum hardware and software needed to build the system. The functional requirement specifies task of the IoT development kit.

The following list is the minimum hardware and software requirement for IoT development kit:

- Raspberry Pi 3
- Virtual Machine with Linux
- Internet connection
- Speaker
- Laravel framework
- Python
- Touch Sensor
- Servo Motor
- Step Motor
- RFID reader
- RFID Card
- IR sensor

Table 5.2 shows the functional requirement of IoT development kit. The functional requirement is identified based on the previous experience on develop museum exhibitions.

Table 5.2:Functional requirement

No	Description
FR1	The hardware should be easy to setup
FR2	The hardware should support different types of sensors
FR3	The hardware and software implementation should support by a document
FR4	The IoT development kit needs low latency during communication
FR5	The Unity3D plugin should be easy to setup
FR6	The Raspberry Pi client should easy to deploy
FR7	The back-end server require authority function
FR8	The back-end-server support real time communication

FR9	The back-end-server should easy to maintain

5.3.2.2 Use Case Diagram

User case diagrams are used to represent the interaction between user and system (see figure 5.5). There are two actors in the project which are user and server. The following Use Case Diagram demonstrates the relationship between different function and user.

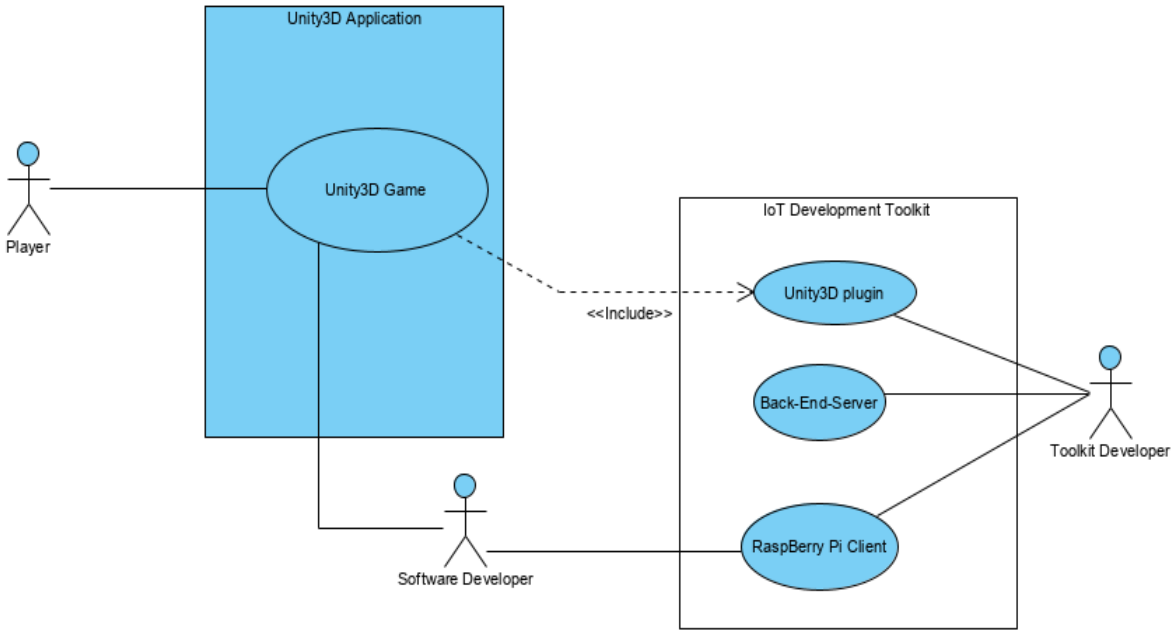


Figure 5.5:User Case Diagram

Table 5.3:User Case Description

No	User Case	Actor	Relationship	Description
UC1	Unity3D Game	Player & Software Developer	Association & Include UC2	The Unity3D develop by software developer, the Unity3D includes a plugin for Mixed reality game development.

UC2	Unity3D plugin	Toolkit Developer & Software Developers	Association	The Unity3D plugin build and maintain by toolkit developer. Software developer receive or sent data through Unity3D plugin.
UC3	Back-End-Server	Toolkit Developer	Association	Back-End-Server develop and maintain by Toolkit developer. The back-end-server bridging the raspberry and Unity3D
UC4	Raspberry pi Client	Toolkit Developer&Software developer	Association	The development and maintenance of Raspberry pi client maintain by toolkit developer. The Software developer following instruction to setup raspberry pi client.

5.3.2.3 Activity Diagram

Activity diagram shows the dynamic behaviours of the IoT development kit. Activity diagrams listed down the workflow of the whole project. There are three activity diagrams for IoT development kit. The following section describes the activity diagrams.

Figure 5.6 shows the whole workflow of IoT development kit. The workflow of IoT development kit can be divided into two steps. In the first step, software developer selects the sensors and connects them to Raspberry Pi. Then, software developers can activate the sensor communication program from the Raspberry Pi client. In the second

step, software developers can load the Unity3D plugin components to the Unity3D editors where the plugin comes with several class files. The developers follow instruction to receive sensor data for game development.

Figure 5.7 shows the workflow of Raspberry Pi component. The first activity is to connect Raspberry Pi with sensor. Software developers can follow document to connect sensor and Raspberry Pi through wires. Once the hardware setup is done, developers can launch Raspberry Pi client script and select the sensor. Software developers need to insert sensor name. The Raspberry Pi will automatic detect sensor data type. If the Raspberry Pi was connected with an input sensor, the client will automatic to emit data to Unity3D client side. The client will maintain a connection to wait for output data from Unity3D.

Figure 5.8 shows the work flow of the Unity3D components. The Unity3D plugin was compiled as a Unity package file. The package file provides an example for developers to understand Unity3D plugin. The first activity is to load the Unity package to Unity3D editor. The Unity plugin package includes class file for communication. The second step is to access class file from Unity package file. The software developers follow the document instruction to access sensor data from Raspberry Pi. Once the developers successfully receive data from example project, they will understand the process of integrating the game elements with the IoT development kit.

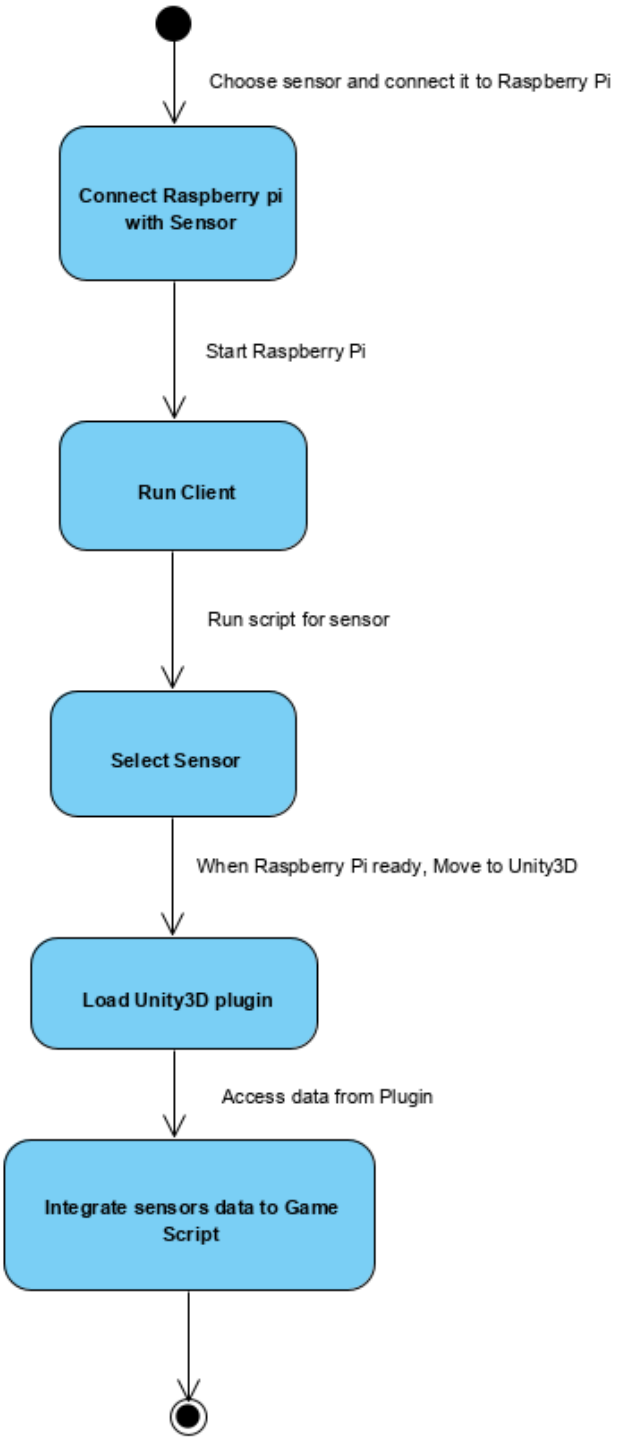


Figure 5.6:Activity Diagram of IoT Development Kit

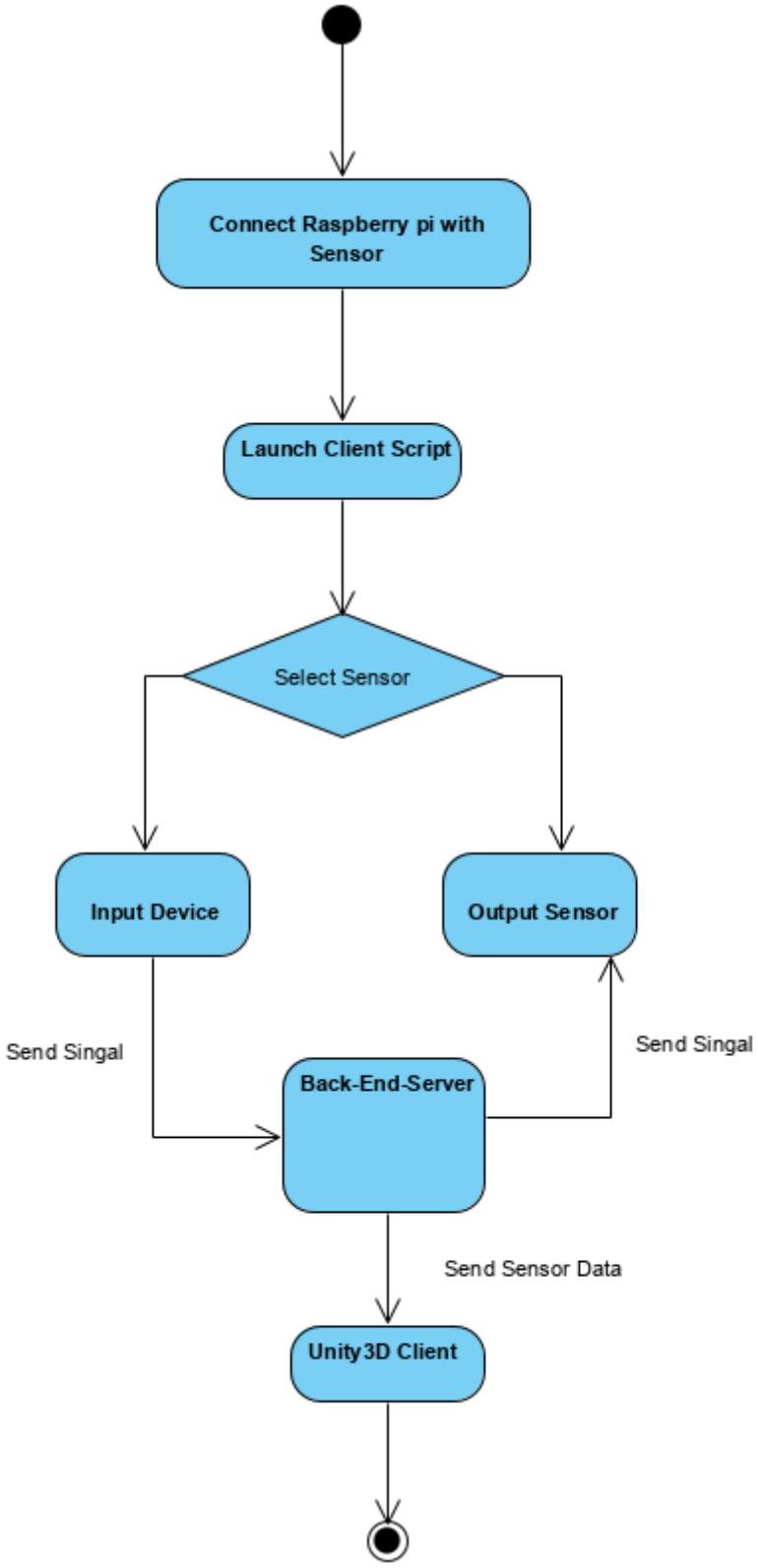


Figure 5.7:Activity Diagram of Raspberry pi Client

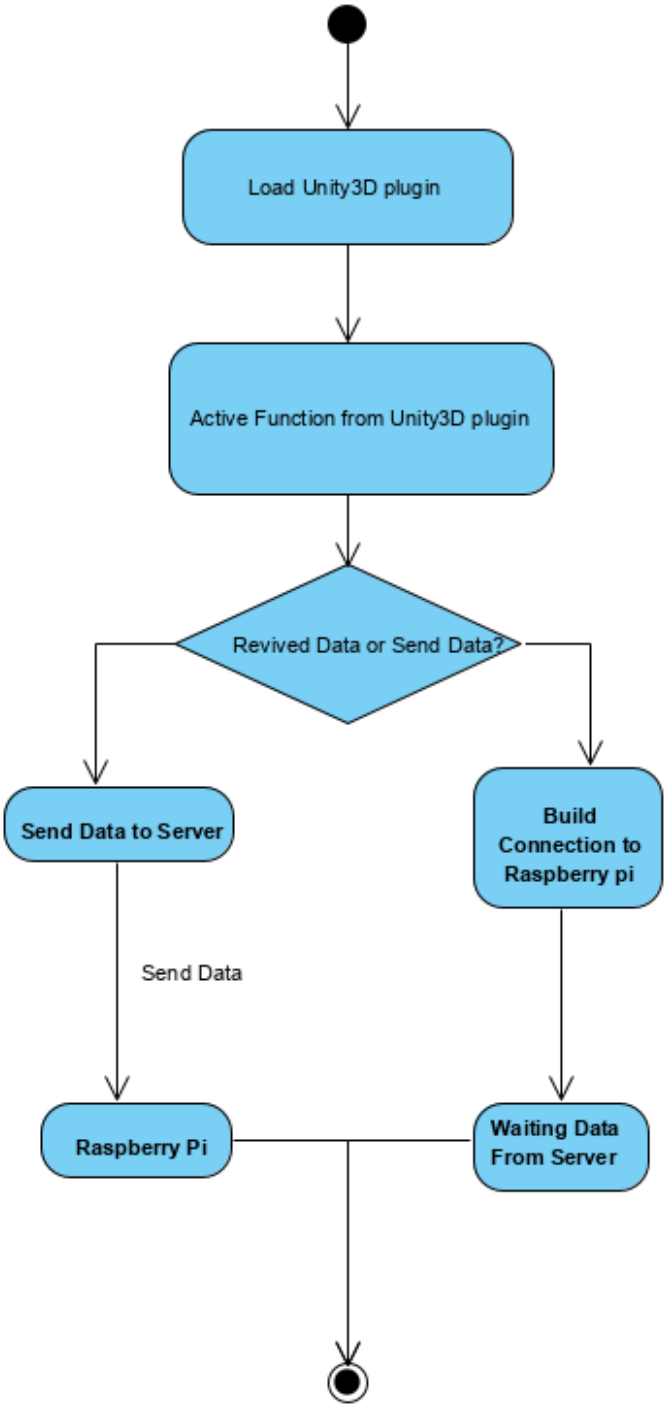


Figure 5.8:Activity Diagram of Unity3D plugin

5.3.3 System Development

5.3.3.1 Back-End-Server Development

The back-end server is used to build real time communication between sensor clients. In this research, it consists of Unity3D plugin and Raspberry Pi. The following figure 5.9 shows the back-end server architecture. The back-end server has four components which are Laravel, Socket.io client, Node.js and Redis. Laravel is one of rapid development web application framework based on PHP. Socket.io is a JavaScript library which allows real time bidirectional communication. Node.js is a famous JavaScript library. Redis is an open source (BSD licensed), in-memory data structure store, used as a database, cache and message broker. These components provide real time communication ability between unity and raspberry pi. This solution similar with mobile notification process. The real time communication is based on WebSocket protocol. For future development, the back-end-server will be available on GitHub as an open source project. This section describes the design and development process of the back-end server.

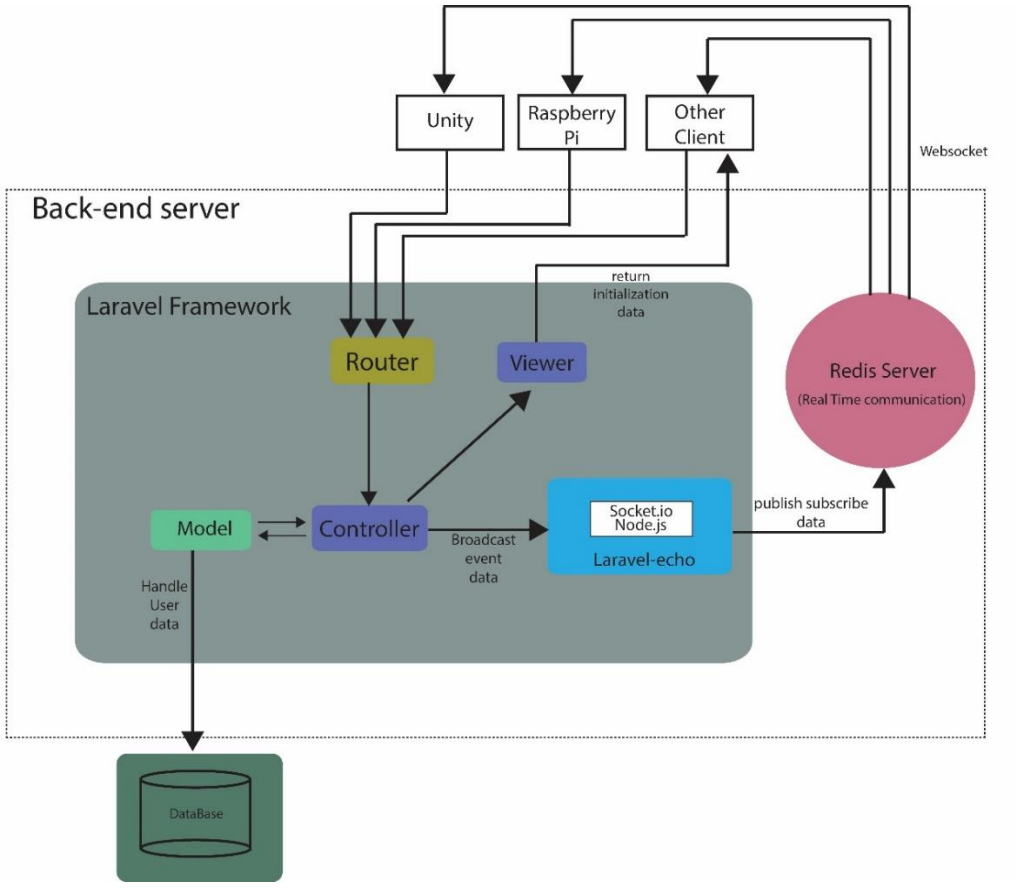


Figure 5.9:Back-end server architecture

The Laravel framework is the core of back-end-server. The framework implemented Model-View-Controller (MVC) design pattern. In the MVC framework, Model is a component that handles the database and algorithm. Viewer is a component that renders data or UI to the client side, such as web browser. Controller receives data from the client side and processes server function. Figure 5.9 shows how MVC framework is implemented in the back-end server. Router accesses data from client and then transfers data to Controller. Client will post data to specific router address to call specific function. Controller will be identifying the data type and run the specific function. For example, if the client side wants to identify user information, controller will check data with Model. In this project, the data and user verify function was handled by Laravel MVC framework.

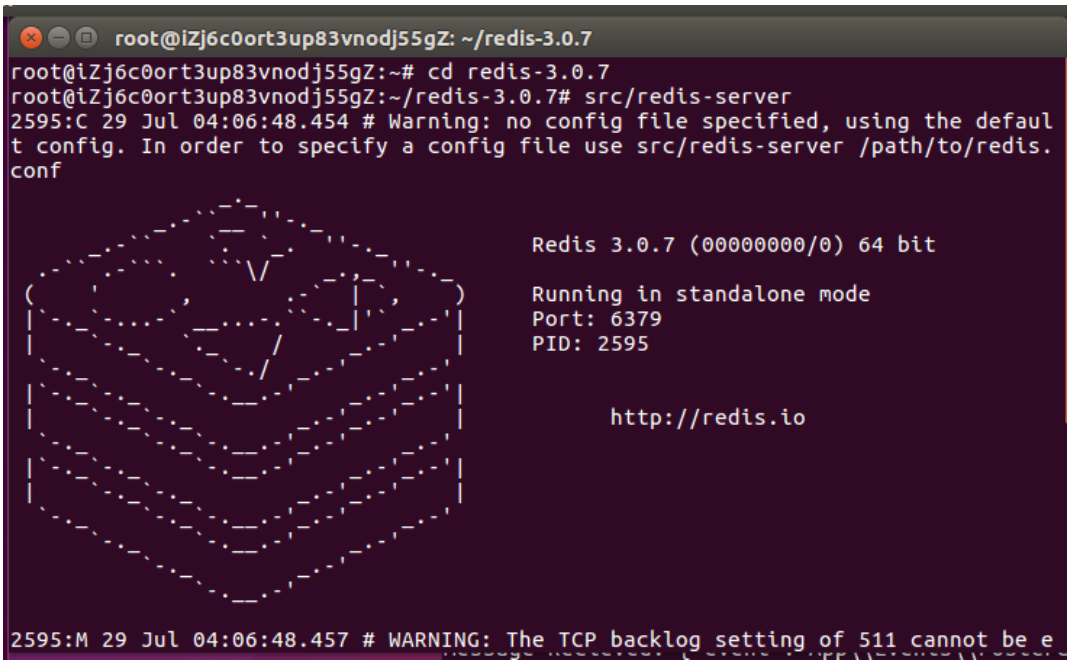


Figure 5.10:Redis Server

The laravel framework plays a role in handling data computing, but the original laravel framework is not able to support real-time communication with Websocket protocol. Therefore, for the real time communication, it needs a middleware component to achieve real time communication. The real time communication was supported by Laravel-echo. The Laravel-echo is a development module that brings WebSocket power to Laravel web application. The Node.js and socket.io were integrated to Laravel-echo as part of the components. During the real time communication, Controller broadcasts data to Laravel-echo module. In the Laravel-eho module, the Node.js and socket.io client will emit data to Redis server. In the end, client will receive data from Redis Server (see figure 5.10).

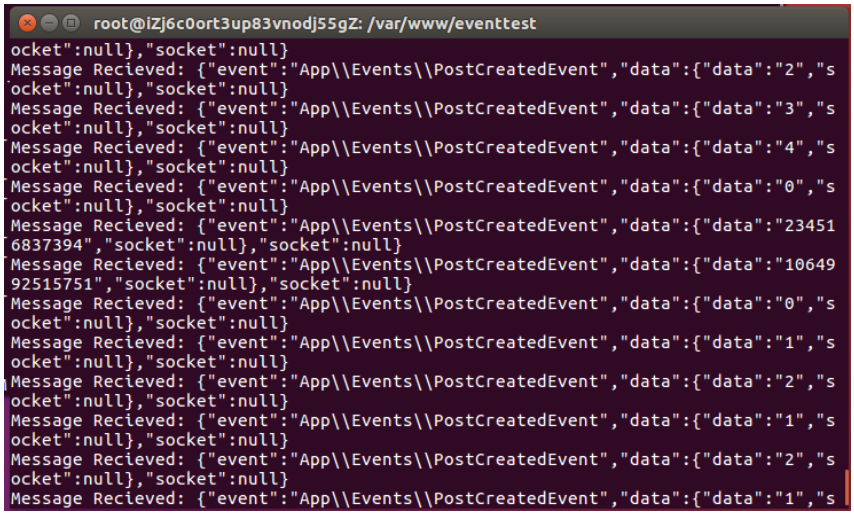


Figure 5.11:WebSocket data on server

The Redis is different with SQL database where the data of Redis is not stored to disk but kept in volatile RAM. The Redis service can be used for real-time applications such as MessageQueue application and phone notification. Redis provides Pub/Sub function for real-time communication. Pub/Sub is a message pattern in software architecture. The senders of message are called publishers. The specified receivers are called subscribers. In the back-end-server, Redis plays the role of exchanging Pub/Sub data. The real time sensor data posts to Laravel framework and is published by the Redis server.

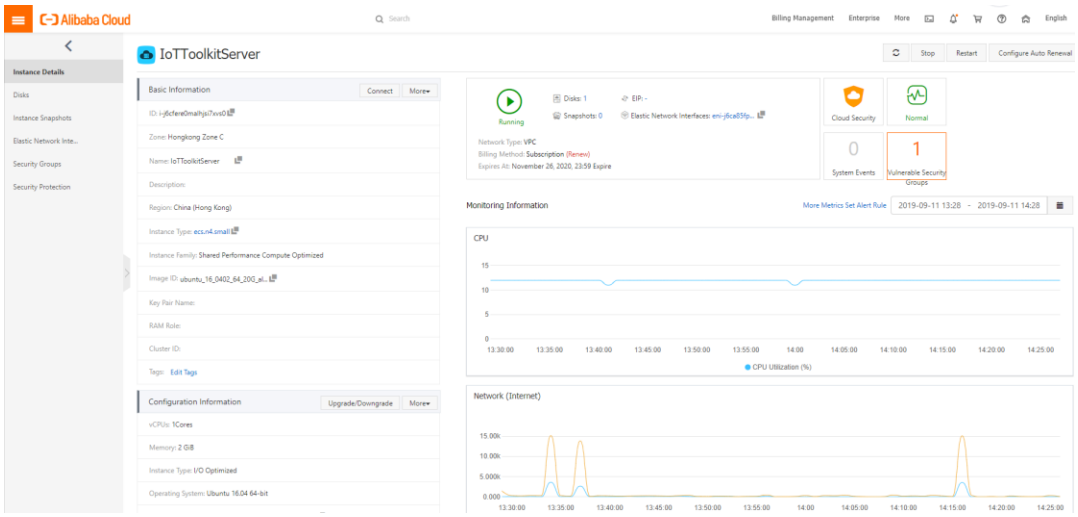


Figure 5.12:Server manager

In the end of development, the back-end-server project was deployed on Alicloud virtual machine service. The operation system of virtual machine is Linux. The virtual machine specification is 2GB RAM and 1 core CPU. The cloud computing service provides a

stable performance of back-end-server. As shown in figure 5.12, the security and diary maintenance of back-end-server is managed on Alicloud developer portal.

5.3.3.2 Unity3D Package Development

The Unity3D plugin helps to simplify data processing from back-end server. During the game development, the developer only needs to drag and drop WebSocket prefab to Unity3D, to access data from plugin library. Figure 5.13 shows the workflow of Unity3D plugin for WebSocket communication.

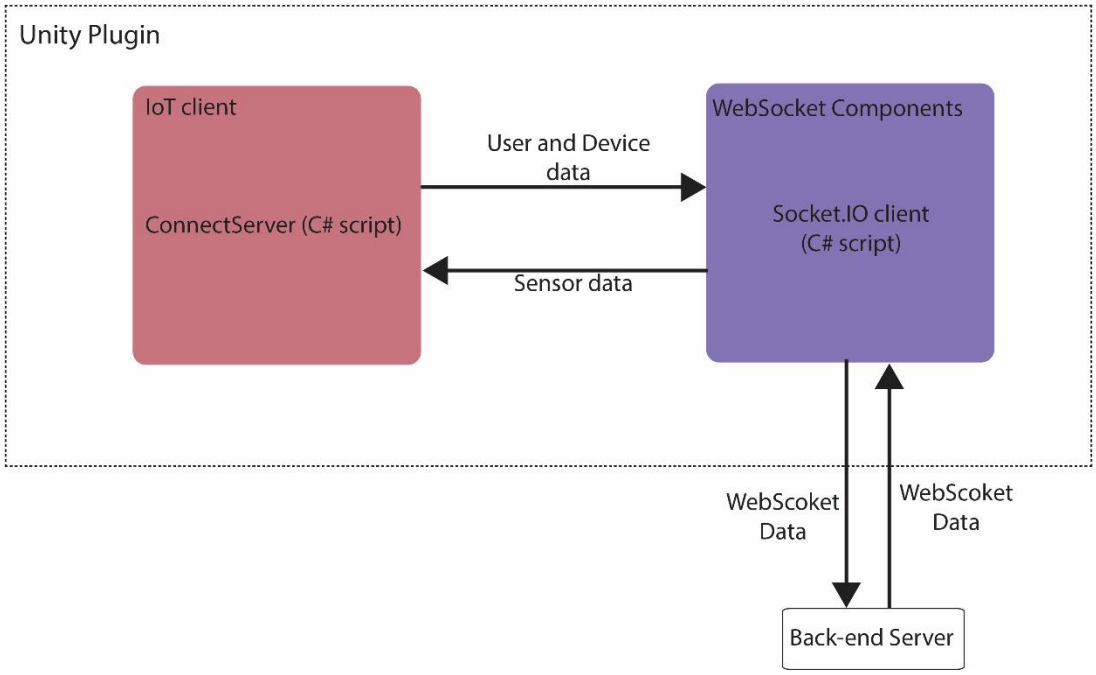


Figure 5.13:Unity3D Plugin architecture

The Unity3D plugin is required to build real-time communication between Unity3D and sensors. The real-time communication was provided by WebSocket method. The WebSocket communication is solved by an open source project from GitHub which call WebScoketSharp. WebScoketSharp is an open source Socket.io client base on C#. The project provides WebSocket communication function for Unity3D. The following list is the workflow of communication between Unity3D plugin and back-end server:

1. Unity3D plugin verifies WebSocket information with back-end server.
2. Unity3D plugin verifies user and device data to back-end server.
3. Unity3D subscribes sensors data from back-end server

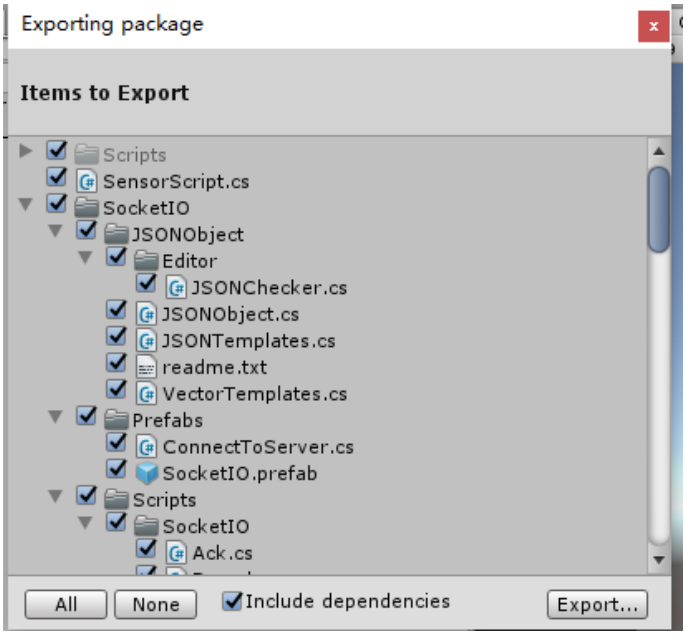


Figure 5.14:Export file to asset package

In the end, the plugin files are exported as Unity3D asset package (see figure 5.14). Figure 5.15 shows the file list of socket.io client and new elements of plugin while figure 5.16 provides example code to access data from back-end server. The following list shows the implementation of Unity3D plugin:

1. Import IoT package to Unity3D project
2. Drag and drop scoket.io prefab to Unity3D editor
3. Check inspector and enter login information
4. Run the project and check data from console
5. Build project with Sensor data

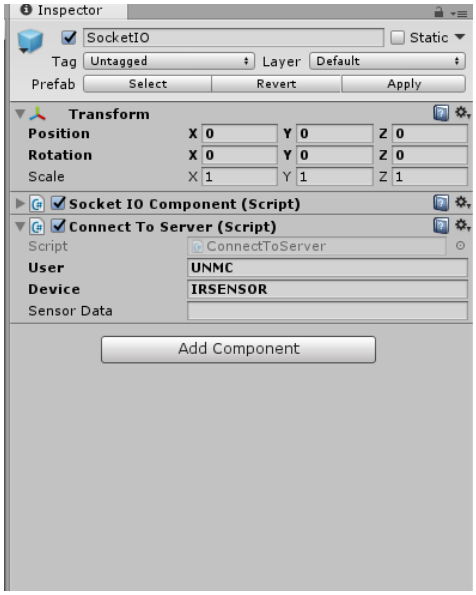


Figure 5.15:Unity3D plugin setup

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class SensorScript : MonoBehaviour {
    public GameObject Sensor;
        // Use this for initialization
        void Start () {

        }

        // Update is called once per frame
        void Update () {
        Debug.Log(Sensor.GetComponent<ConnectToServer>().SensorData.ToString());
        }
}
```

Figure 5.16:Example code to access data from back-end server

5.3.3.3 Raspberry Pi Client Development

The Raspberry Pi client was developed by Python. The sensor toolkit includes 10 sensors and is shared on GitHub. These sensors can easily be purchased from online shops, such as eBay or Taobao. The developer only need to connect sensors to Raspberry Pi and run the Raspberry Pi client during the development. Figure 5.17 is one of the instructions for the setup of Raspberry Pi client. The left diagram is the instruction to guide users to connect Raspberry Pi and sensors. The right diagram is the Python script to launch sensor. When the sensor is active, the sensor starts to emit data to back-

end server. The use of the Raspberry Pi client reduces the development time to develop mixed reality game.

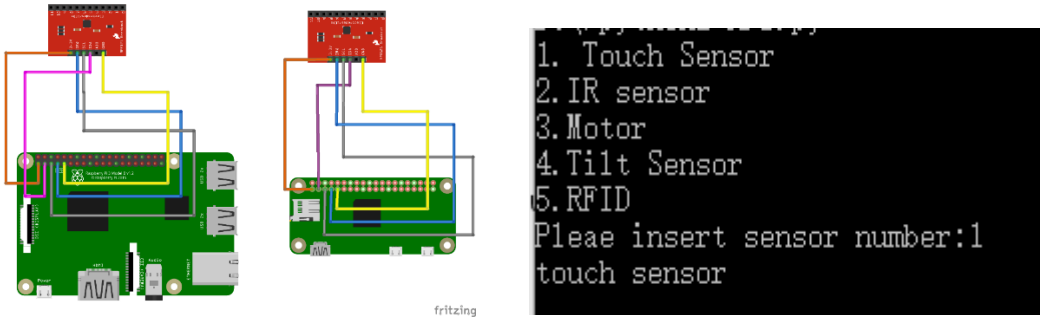


Figure 5.17:Raspberry Pi hardware and software setup

Figure 5.17 shows the Raspberry Pi client structure. The Raspberry Pi client is developed by Python. Conventionally, the developer needs to connect sensors and Raspberry Pi, then program a script to solve the communication issue between sensors and client. In this research, the Raspberry Pi client integrated the communication function from different sensors. The sensors function was handled by a main function. The main function controls the logical part of the program such as the transfer of data to post function. When the sensor data is ready, Post data function will post data to back-end server through JSON format. In addition, the Raspberry Pi client implemented Socket.io to communicate with back-end server.

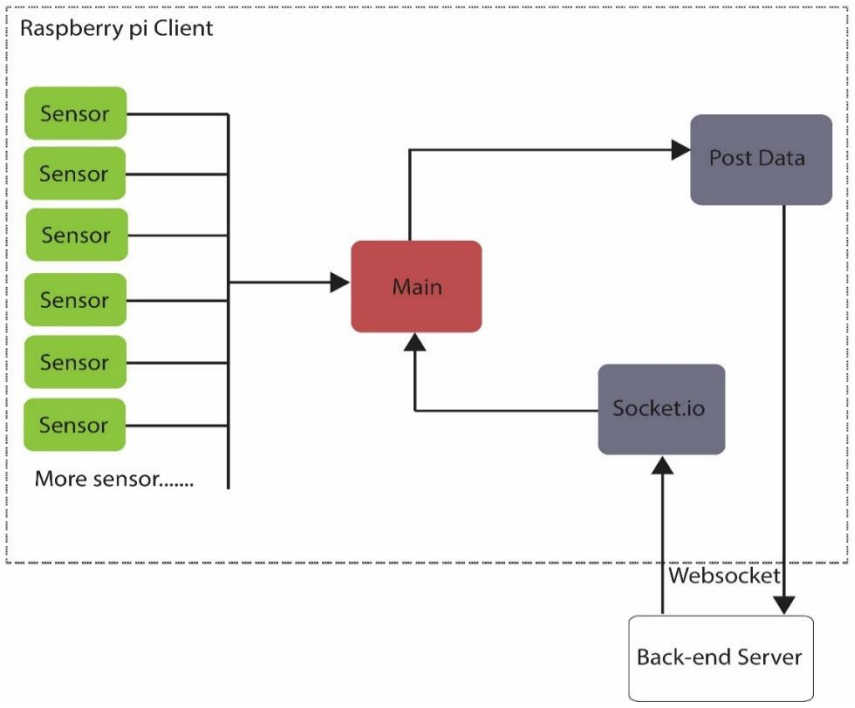


Figure 5.18:Raspberry Pi client structure

5.3.4 Result of Evaluation

5.3.4.1 First User Trail

The evaluation of the IoT development kit consisted of two user trials. The evaluation goal of the user trials was to evaluate the usability of the IoT development kit and its effectiveness in supporting the development of a (prescribed) simple IoT game. The first user trial was conducted with 25 industry and university researchers and developers in the UK and Malaysia (see figure 5.19). A design iteration was carried to create a second version of IoT development kit based on the result of the first user trial. A second user trial was carried out as a workshop involving Computer Science major undergraduate students as part of a Human-Computer Interaction module class. The second user trial aimed to provide a stable version of IoT development kit for developers to use to develop their own IoT game system.

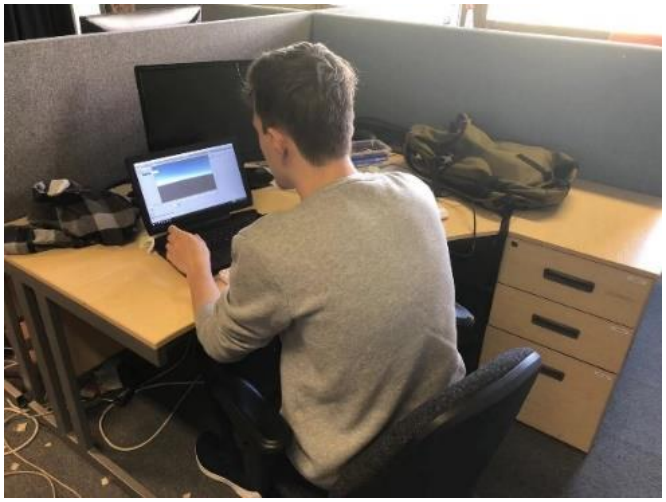


Figure 5.19:Evaluation conducted in a university lab

The first user trial involved three tasks: 1) The participants have to follow instructions to setup and deploy a Raspberry Pi client as shown in figure 5.20. 2) Then participants have to build a test file on Unity3D for communication testing. 3) Finally, they are required to build a simple game with the IoT development kit. For those developers with no programming experience, the project provided a basic tutorial for them.



Figure 5.20:Evaluation in a workshop

The result of evaluation was collected by survey questionnaire and user observation. The evaluation question covered participant demographic and information on their technical expertise and their feedback on the effectiveness of the IoT development kit.

5.3.4.1.1 Participant Demographics

The survey feedback included information on the programming experience of participants. There were 25 participants who participated in the first user trial involving 16 males and 9 females. The questionnaire survey used 10-point scale with 1 representing “very inexperienced” and 10 “very experienced”. Figure 5.21 shows the different levels of programming experience of participants. There were 44% of participants without any development experience with Raspberry Pi (see figure 5.22) and Unity (see figure 5.23) respectively. Overall, the IoT development kit aims to provide a rapid development kit for those programmers without hardware development skills.

On a scale of 1 to 10, how do you estimate your programming experience? (1:Very inexperienced 10:Very experienced)

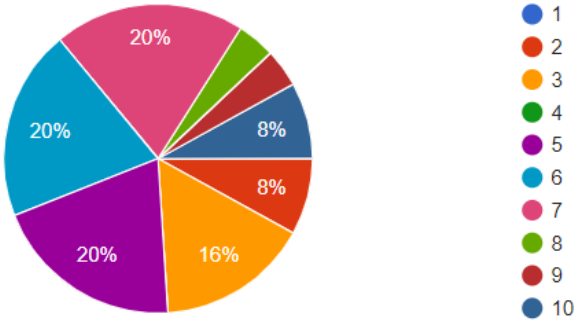


Figure 5.21:The survey of programming experience

How experienced are you with the following development tool: Raspberry Pi (1:Very inexperienced 10:Very experienced)

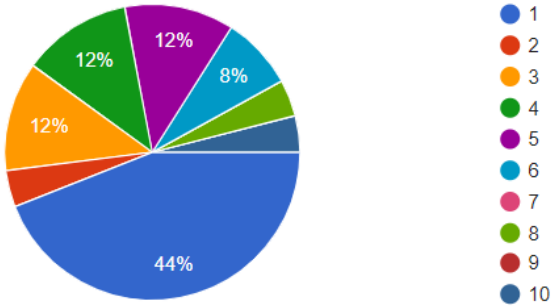


Figure 5.22:The skill level of Raspberry pi

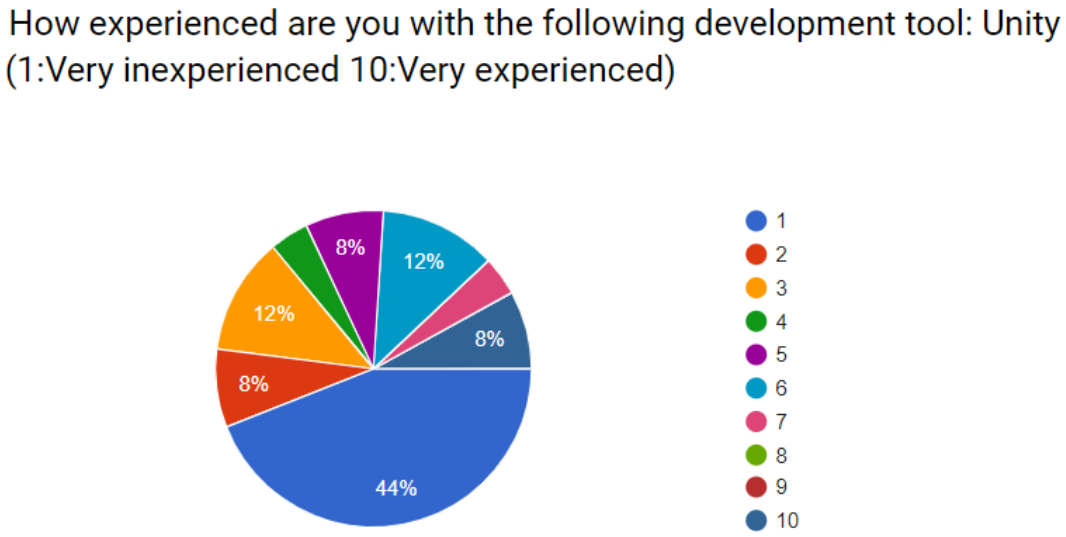


Figure 5.23:The skill level of Unity

5.3.4.1.2 Survey Question

The questionnaire survey used 5-point Likert scale with 1 representing “I strongly disagree” and 5 as “I strongly agree”. Table 5.4 shows a set of questions for the first user trial with results in arithmetic mean and standard division. Question 9 required participants to estimate the time required to build similar task conventionally without using the IoT development kit.

Table 5.4:Results of IoT development kit survey

Question	Pilot Study	
	Mean	SD
Q1. The hardware instruction is easy to understand.	4.36	0.624
Q2. The IoT toolkit inspire me to develop mixed reality game.	3.84	0.88
Q3. The Unity plugin document is easy to understand.	4.20	0.70
Q4 The IoT toolkit gives me confidence to create more mixed reality game.	4	0.74
Q5. I can easily setup sensors with raspberry pi with toolkit instruction.	4.20	0.89
Q6. I can easily activate sensors with python script.	4.08	0.744

Q7. Unity plugin helps me receive sensor data more efficiently.	4.12	0.50
Q8. The code of Unity plugin is easy to access.	4.28	0.53
Q10. The IoT toolkit reduce the development time.	4.32	0.67

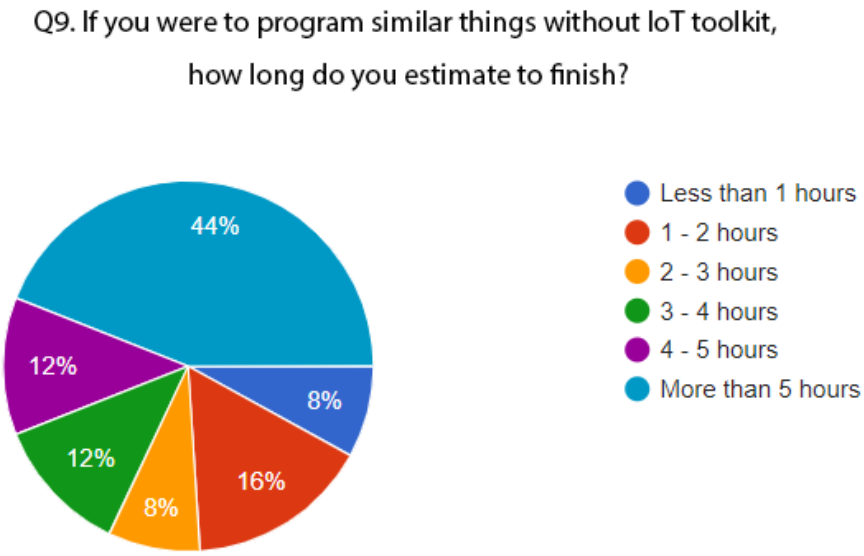


Figure 5.24:Estimated time to create simple IoT game without using IoT toolkit

Overall, the pilot user trial received positive feedback from participants. Based on observation, some participants were confused with Raspberry Pi setup diagram, which had since been redesigned in the second user trial. Participants felt easy to solve task with instructions (Q1: M=4.36, SD=0.624; Q3: M=4.20, SD=0.70; Q5: M=4.20, SD=0.89;). Most participants agree that the Raspberry Pi client is easy to active and Unity3D plugin is easy to program (Q6: M=4.08, SD=0.744; Q7: M=4.12, SD=0.5). In the question relevant to performance, most participants agreed that the IoT development toolkit helps to reduce development time (Q10: M=4.32, SD=0.67). The figure 5.24 shows that more than 44% participants think that they would need more than five hours to develop similar IoT games without the IoT development kit. In contrast to existing, conventional development, most participants solve all three tasks in less than one hour having used the IoT development kit.

5.3.4.2 Second User Trail

The second user trial was conducted as a follow on to the IoT card game evaluation as part of the HCI module class where students used the IoT card game to brainstorm ideas

to solve a design challenge and then were given an option of using the IoT development kit to build their IoT game prototypes. Two group of students chose using the IoT development kit to build their interactive prototypes, while the other five groups built their prototypes using low fidelity prototyping method. The two groups who used the IoT development kit successfully built a fully functional and interactive prototype as described below:

1) Oil works simulator - The oil works simulator simulates the control of flow of oil fluid that passes along it (see figure 5.25). The developed prototype provided a turnable wheel to control the flow of oil which triggered a projected oil level visual representation when the wheel handle was turned. Eventually, the prototype would reset the animation to the beginning phase where the oil's height is at its lowest level if the infrared sensor does not detect any changes and turns of the wheel.



Figure 5.25:Physical components of oil works simulator

2) The augmented Christmas tree – The prototype exhibit used a pressure sensor to activate a digital projection and sound onto a pipe surface (known as a Christmas tree on the oil rig platform) whenever a visitor passes by the exhibit (see figure 5.26).

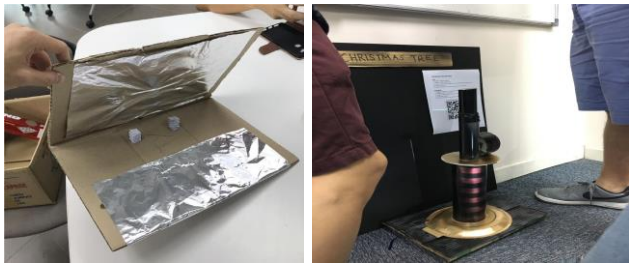


Figure 5.26:The prototype of augmented Christmas tree using pressure sensor and a Raspberry Pi to connect it to the program

5.4 Conclusions

This chapter presents the IoT toolkit which consists of an IoT card game and an IoT development kit to help future designers design and develop IoT serious games in museum settings. The toolkit proposes a card game solution for IoT serious game design in museum, consisting of 90 cards grouped in 5 categories for idea generation: Asset Card, Engagement Card, Serious Game Card, IoT Card and Possible Issue Card. The project conducted two user study workshops with undergraduate students, majoring in Computer Science. Results of evaluation showed that the card game was useful in guiding non-experts in quickly generating ideas for IoT serious games. In addition, the card game supported creative thinking and collaboration among participants. The contribution of this research is a card game that can help museum curators and designers generate IoT serious games to engage with visitors in a deeper way to cater for the changing role of museum.

The IoT development provides a solution to help software developers build IoT serious game by filling up the gap that existed in hardware and software communication. The IoT development kit was evaluated in a user trial to evaluate its usability and performance. In addition, the IoT development kit was used to build functional interactive prototypes as part of a HCI module. The contribution of IoT development kit is a rapid development tool that reduces the setup complexity and development time for IoT serious game. This will allow more IoT serious games to be developed to provide unique physical and digital social experiences that can lead to an increase in visitor engagement in museums.

Chapter 6. Discussions

6.1 Pilot Project

6.1.1 Baba Nyonya Heritage Museum Pilot Project

The pilot project carried out as part of research collaboration with Baba Nyonya Heritage Museum resulted in the design and development of two interactive exhibits – the Batu Boh simulator, a smart grinder replica embedded with IoT technologies and the Goldsmith simulator, a virtual jewellery making simulator developed using Leap Motion and sensors. At this early stage, a public user trial confirmed their effectiveness in improving learning gains where the percentage of correct answers increased from 54% to 82%, The comparison questionnaire results between the two Batu Boh and Goldsmith exhibits showed that more participants agreed or strongly agreed that the Batu Boh simulator provided a good learning experience, and helped them reflect on their own culture than the Goldsmith simulator. User observations showed that the Batu Boh simulator was more successful at engaging participants and bystanders than the Goldsmith simulator. It was observed that while users were engaged in physical interactions with the Batu Boh system, some may not have paid full attention to the audio stories recounted by 'chef' as they tended to be engrossed with carrying out the grinding task. In the subsequent design iteration, the Batu Boh simulator was re-designed to include short audio intervals where users would just listen before continuing with the next physical task. Even though through the user feedback, users had suggested adding even more physical interactions in the exhibit designs, the project sought to find a balance between providing an enjoyable learning experience and one that further supports social experience and reflection. Previous research had widely used mobile applications and tangible user interfaces to provide narrative content for visitors. However, these are essentially electronic labels rather than a new modality of interaction. As shown in figure 6.1, the narrative modality of smart replicas systems and mobile applications are active multimedia content through electric labels. In contrast, the Batu Boh supported more physical interaction than previous smart replicas and mobile applications, suggesting the potential of using IoT technologies to create physical exhibits that can provide more engaging learning experiences.

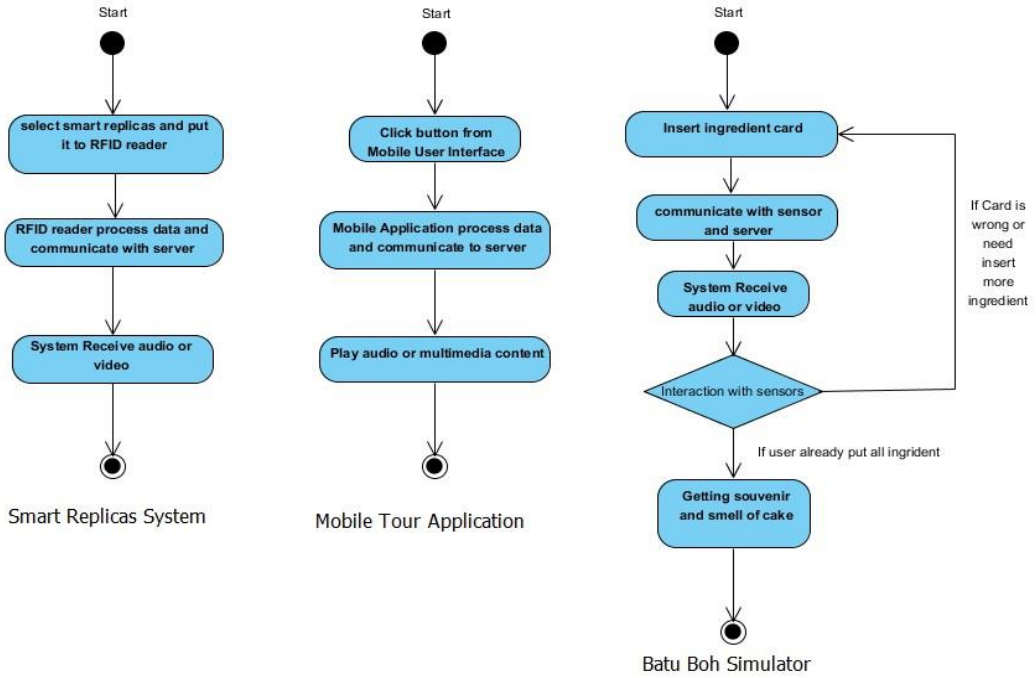


Figure 6.1:Differences in activity diagram between smart replicas, mobile tour app and Batu Boh simulator

6.1.2 Supporting Multi-Sensory Experience

The pilot project mixed physical and digital interactions to create a multi-sensory learning experience for visitors by incorporating the following design input and output modalities:

- Batu Boh: Input-tagged cards and physical motion; Output-audio, smell and physical souvenir
- Goldsmith: Input-hand movement/gesture, physical movement and camera photo; Output -visual

Some participants remarked liking the smell interface, but most of them could not correctly identify the type of ingredient in which the fragrant belonged to or relate it back to a smell that would come from an ingredient used in the recipe (different recipes will permeate different ingredient smell). Although, the smell interface was a nice addition to enhance the experience of the user, it did not evoke memories or encourage discussions or reflections as initially hoped. Neither users from the same group, noticed the different smell emitted when different '*kuih*' was made. This suggests that the smell interface is poor at supporting reflection, but good at engaging the users.

In the Batu Boh simulator, it dispensed capsules with '*kuih*' stickers inside as physical souvenirs, while the Goldsmith simulator provided users an option to take a photo of them wearing the virtual coin pendant they made and to download it as a digital souvenir. The physical souvenir was found to attract a lot of attention from visitors and encouraged them to try out the Batu Boh exhibit, and even more than once. The users could receive one of the four '*kuih*' stickers to represent four different recipes depending on which they choose to make. It was observed that users from the same group would show each other the stickers that they received. However, little discussions or exchange of words were observed e.g. to compare and talk about the different '*kuih*'. The Goldsmith digital souvenir was found to be less interesting than Batu Boh's physical souvenir. Most users were shy to take their own photos in the public space or for fear of privacy issue (e.g. not wanting photo to be uploaded to the museum server). Most of those who took the photos, also did not bother to download the digital photo souvenirs using the QR code. While there has been research into the role of data or physical souvenirs in helping to aid in personal reflection, this pilot study suggests that physical souvenirs seemed to hold more promise than digital souvenirs in supporting this design goal.

6.1.3 Improving User Engagements and Reflections

The results of pilot study suggested that the use of IoT technology has potential to improve user engagements and reflections. However, the result showed little evidence on lower level reflection. Many family groups felt that current exhibits did not support enough communication and discussions among members. In addition, the exhibits can only be used by one user at a time and present only one aspect of cultural history / story e.g. food or jewellery. In the following iteration of research, the project strived to improve cultural reflections by incorporating serious games.

As described in previous studies, serious game is a type of game with education as motivation. A serious game consists of many elements, such as storyline, roles and background. There were previous examples of serious games being developed to help people learn about culture at home (Laamarti, Eid and Saddik, 2014). However, they were developed mostly on virtual platform, such as computers and mobile phones. The game elements can be used to help players understand the entire culture, various aspects at the same time. It can also support multiple players. For instance, serious game may consist of a virtual world for players where they get to choose their own characters and simulate social life with other players.

The next phase of research focused on creating IoT-based serious games to further improve user engagement and more importantly reflection. It extended current exhibits to include other smart replicas to establish a physical role play game environment for users. For example, the physical serious games would have different tasks for players, requiring them to discuss and reflect more. At the end of the game, each player would receive a physical souvenir to aid their personal reflection. The project aimed to contribute towards establishing an IoT serious games toolkit and design guideline to help designers and museum curators design physical serious games more efficiently and in less time.

6.2 Main Museum Study

The second stage research was guided by seven design goals to better achieve the aim of encouraging reflection by applying IoT serious games concept. This section involves discussion on the results of evaluation relevant to each design goal.

DG1 - Connecting past with present: The purpose of design goal is to better link the historical origin of Peranakan culture to the present day in Peranakan museum. Through the pilot results, the pre-learning session showed that most visitors did not have much knowledge about the Peranakan culture before the museum tour. Therefore, a pre-learning serious game had been designed and incorporated into the learning experience to connect past history with the museum tour. The trading game provided a chance for visitors to understand how Peranakan culture grew through trading businesses at the port of Malacca. The trading game was found to be effective at drawing children's attention. The serious game and IoT physical setup further linked the storyline and helped visitors understand the relationship between Peranakan culture and the house. As a result, children focussed on the museum artefact during tour. Result of evaluation showed that participants enjoyed the pre-learning game and asked their parent to download for them.

DG2 - Supporting role play for self-immersion: The interactive exhibits allowed users to get into characters and immerse themselves in past activities. In the virtual games, it provided a chance for visitors to experience how businessmen traded and settled down in the port of Malacca. The physical interaction setup provided a chance to experience being a goldsmith or a cook. In the end, the roleplay allowed visitors to gain new Peranakan experiences as they explore the relationship between the artefact and culture. The roleplay for self-immersion support dialogic reflection (level 2) and transformative reflection (level 3) as it supports the exploration of relationships between

artefact and their real life. In the survey, 96.4% of participants agreed that the IoT serious game created an immersive experience for them (see table 4.5).

DG3 - Bridging physical and digital world: The design of IoT serious games take the benefits of both physical and digital game world and elements. The merging of physical and digital game play helped create a new museum tour experience for visitors. For example, the result of evaluation showed some participants were surprised when the design of their coloured in lantern paper were projected onto the physical lantern and also shown in the virtual Peranakan house. The physical design and virtual lantern as a souvenir was a good way to encourage discussion and encourage their peers to try out the game. The advantage of bridging physical and digital worlds is to attract attention from participants but still keep the attention on the artefact.

DG4 - Personalisation of artefact: In most museums, artefact are an important asset to them. Some artefacts could be hundreds or thousands of years old. The research explored creative ways to engage visitors with the Peranakan artefact through the use of digital projection or mock-ups. For example, the lantern visual projection system allowed participants to design their own lantern. Then they could insert their design into a vision capture box. The vision capture box would capture the design and project it onto a real lantern. Through this activity, participants could understand the history of Peranakan and role of lantern while designing their own lantern. At the same time, the projection allowed participants to share their designs with others in the public space. Through the virtual house design, participants could print out the design and bring it back to share with others.

DG5 - Providing physical interaction for engagement: In the early stages of game development, a development team should identify the museum assets, such as types of artefact, types of culture heritage and space etc. Each museum may have different assets, and some artefact may not be touched. They should be identified to help developers understand what kind of content may be virtual or physical. This process could help curators and designers integrate most suitable museum content and story to the IoT serious games. For example, when children interacted with the Batu Boh and get a physical souvenir, it created an enjoyable social experience for the entire group and an immersive role-play experience for the individual user. The pilot and main result of evaluation showed that young users prefer more physical interaction in the museum tour. Result of survey and interview showed that physical interaction can give

participants a new understanding of Peranakan culture to trigger deeper levels of reflection.

DG6 - Creating opportunities for sharing thoughts. For design goal 6, a comment system was designed into the virtual Peranakan house activity to allow participants to share any thoughts when they completed their tour. Unfortunately, there were only 1 participant who commented on the system. It seemed that participants would not openly share their thoughts as it was an optional feature in the system. However, the post-visit interviews showed that some participants had discussion after the tours, which achieved level 3 reflection which is to form a new point of view on culture. The shared immersive experience provided points of discussion among family members.

DG7 - Providing physical souvenirs for post-visit reflection. Participants would receive two physical souvenirs during the tours. One is a physical souvenir from the Batu Boh station. The other is a print out of their decorated virtual Peranakan house consisting of all the items they collected during the tour. The physical souvenir from the Batu Boh station was the most popular with children. However, they were not very interested to get the print out of virtual Peranakan house, though most were more interested in the activity of decorating the house itself. This could be that getting a print-out paper is less of a novelty to them.

6.2.1 The Challenge and Potential of IoT Serious Game

The increasing deployments of IoT technologies are opening up new avenues of research and deployment opportunities for game design for museums. IoT games have a huge potential role in activating and connecting the physical objects in the world around us and providing unique physical and non-digital social experiences that can be designed for play in museums. However, the pilot and main museum studies revealed that idea generation for game design and IoT technology is a big challenge as also noted by previous research (Kultima et al., 2008; Hughes and Moscardo, 2017; Mora, Gianini and Divitini, 2017). There was also the challenge of incorporating the reflection theory by Fleck and Fitzpatrick (2010) into the design of storyboard. A huge amount of time was needed to be spent understanding how to use the museum and its rich collections as a game space as well as interaction possibilities that IoT technologies offer.

A museum curator may have limited knowledge on, for example, game design and IoT, while a developer may not have experience of curating museum content and artefact. A

museum design team comprises experts including museum curators, educational experts, visitor representatives, volunteers, and designers and developers of various multidisciplinary backgrounds, with a wide variety of perspectives and stakes. As such, the concept development phase may take a long time in order for the group to establish the main message, themes and learning goals and have a clear understanding of different factors affecting user experience as well as user engagement possibilities. For example, in order to design an IoT serious game for a museum visitor experience, typically a considerable amount of time and effort is needed to convene a series of facilitated brainstorming workshops to brainstorm ways to present the content and artefact and a team of end-user representatives may work with developers to generate user stories (Wakkary and Tanenbaum, 2009).

To overcome this, there is a need to use a tool to support and accelerate the process of ideation of IoT serious games for museums. Previous research proves that card-based tools are useful for ideation (Paulus, 2000). So far, existing card games support game design or IoT product design, but none bring these domains together to support idea generation for IoT serious games in museums (Mueller et al., 2014). Therefore, the study proposed a card-game solution synthesising design knowledge of IoT serious game design in museum with the following main objectives: 1) to improve idea generation efficiency of museum curators and game designers, 2) to help non-experts understand IoT technology and game design, and 3) to improve visitor engagement with valuable museum content and artefact.

In terms of technical challenge, having reliable and good network connection to the internet is one of the main challenges of implementing IoT serious games in museums. This was faced in the museum trials at the Baba Nyonya Heritage Museum as it had very poor WI-FI coverage. As the developed interactive exhibits were situated at various locations in the museum where some were out of the WI-FI coverage, the project had to explore alternative solutions such as by using QR code and WI-FI hotspot. For example, at the Batu Boh station, visitors could scan a QR code which they can find inside a dispensed souvenir capsule to redeem a virtual item to decorate their virtual Peranakan house. In addition, the integration of hardware and software to create IoT interactive game installations has a steep learning curve for most software programmer. While a lot of IoT development resources may be found on Internet, there is a lack of software toolkit that helps to build the data communication between Unity game platform and IoT devices such as Raspberry Pi. Hence, the project contributed to designing a server based on MVC model to exchange data for Unity client and IoT devices. For instance, Zhao et al. (2018) proposed a VR touch project to provide touch feeling of object for players, but

without any interaction with the virtual system. With an IoT development kit, the VR system could easily build interaction between physical object and virtual system. Therefore, as a solution, the next phase of research proposed an IoT development kit to reduce the development time and learning curve of IoT serious game. The IoT development kit provides the benefit of real time communication between Unity and IoT devices future IoT development.

In comparison to traditional museum tour and serious games, the main advantages of using an IoT approach to develop serious games are the physical affordances that come from interacting with smart objects or augmented artefact and the ability to connect them together e.g. networked exhibits sharing data through the IoT cloud server to curate deeper narrative. The IoT approach provides a flexible game design structure with potential for high expandability. Since the virtual game is deployed on a cloud server, this allows museums to add new content or 'game station' in future. This provides an opportunity for extended storytelling where the learning content builds on top of one another or just to provide contrasting perspectives to trigger curiosity and reflection as part of the museum game experience. Inadvertently, the creation of an immersive storytelling experience will help visitors develop deeper understanding of the culture, further aided by personalized data capture and sharing to encourage self-reflection. For example, in the main museum study, the trading game station was designed to provide context and basic knowledge of the origin of Peranakan culture. Then players went on from station to station to collect virtual items through role-playing e.g. being a goldsmith or a chef in order to decorate their virtual Peranakan houses with the collected and personalized items, which became sources of discussion and reflection.

The use of augmented artefact also helped link the history behind a culture and present. The physical interaction with the augmented artefact were not only enjoyable but also served as trigger to facilitate discussion among family groups. Although most of these exhibits only allow single user interaction, they also serve to provide group experience allowing the entire user group e.g. family group to watch and experience the physical interaction together. For example, in the Batu Boh station, many examples of family groups enjoyed the group experience with the augmented artefact which led to instances of intergenerational discussions. Similar to the research by Ghajargar et al. (2018), they have explored user relationships with augmented artefact, namely: *augment me*, *comply with me,* and *engage me* and proposed another example to support reflection of a user by creating the model of *make me think* relationship that is engaging, transformative, communicative, and deliberative. The research suggested that in IoT systems designed to support reflective thinking, the sensory and physical characteristics of the artefact itself

play crucial roles—e.g., its behaviours and affordances, and reflective thinking can be considered as a reference task (e.g. an ongoing activity to be continuously supported) in HCI itself. As such in section 8.2.3 this project attempts to propose more design guidelines for helping future developers in designing IoT serious games to support reflective learning.

Many research attempts have also been made to support end of museum tour reflection. For example, Petrelli et al. (2017) uses a data souvenir in the form of a postcard with instructions to access a website as a means to collect user-generated content. However, the number of visitors accessing the online experience was found to be low. ArtLinks is another example that uses a standalone visualisation display associated with an exhibit to encourage visitors to share their thoughts and reflect on their visit (Cosley et al., 2008). However, visitor expectation of the system was that it should have provided informational elements to lead into social and reflective elements. Giaccardi and Palen (2008) presents the use of social media platform to support discussion among visitors. Based on the reflection framework by Fleck and Fitzpatrick (2010), revisiting an event or knowledge is an important condition to supporting deeper level of reflection. Compared to all the above approach, the IoT approach is able to support this by allowing visitors to revisit the cultural content (combined with captured and shared visitor data) at the end of the museum experience. For example, at the end of the main museum study, participants could decorate a virtual Peranakan house with personalised items that they collected along the game experience. Although there was a ‘share your thoughts’ function in the virtual space, it was rarely used by participants. Similarly, the print your virtual house as a physical souvenir feature was also less popular. However, since participants enjoyed designing the virtual house, the house decoration game has potential to be developed into a bigger virtual world to create a small community of visitors who could replay the game and communicate with other visitors in the virtual game world.

6.2.2 The Potential of IoT Serious Game to Design Reflection

Reflection is a process designed to promote the examination and interpretation of experience and the promotion of cognitive learning. It is the process of looking back on the implications of actions taken and determining what has been gained, lost, or achieved and connecting these conclusions to future actions and larger societal contexts. What are the benefits of reflection? Critical reflection promotes personal development by enhancing visitors’ self-awareness and their sense of community. Transformative reflective is important to help transform our take-for-granted frames of reference (e.g. perspectives, habits of mind, mind-sets) to make them more inclusive, open and

emotionally capable of change and this may lead to respect for others, self-respect, willingness to accept responsibility for the common good, willingness to welcome diversity and to approach others with openness (Mezirow, 2000). In times of increasing ethnic tensions throughout the world, the role of museums as repositories of heritage is ever more important to help people understand cultural similarities and appreciate cultural differences. Thus, designing visitor experiences that can support cultural reflection that will lead to respect for one another and deeper appreciation of unity in diversity is becoming an important research theme.

Since Fleck and Fitzpatrick's framework (2010) has previously been applied to evaluate reflection in contexts such as teaching (Fleck, 2010), there was no pre-existing evaluation scheme on cultural reflection in games. Hence, the project adapted Fleck and Fitzpatrick (2010) based on the museum design context as follows: 1) Reflective description (Level 1) requires the IoT serious game to help players understand the origin of culture. 2) Dialogic reflection (Level 2) requires the IoT serious game to encourage participants to explore the relationship between the history and artefact or exhibition. 3) Transformative Reflection (Level 3) involves helping participants develop new or deeper understanding of culture 4) Critical Reflection (Level 4) involves extending the thinking to wider societal topics.

In a related study, Mekler et al. (2018) applies Fleck and Fitzpatrick (2010) reflection framework to games. The study explores players' day-to-day game reflective experiences and concludes that while reflective description, followed by dialogic reflection were evident in participants' accounts, there were very few instances of transformative reflection and no instance of critical reflection, the higher levels of reflection outlined by the framework. In contrast, the IoT serious game was developed and evaluated with the same reflection framework, however with specific game context and content to trigger high level of reflections. Design goals as discussed in section 8.2 were applied, which evaluation results showed some success in achieving all levels of reflection. Based on the experience of designing both museum studies in this research, below further discusses how reflection was facilitated by the IoT serious game:

1. Enhancing engagement: Designing the IoT serious game to be engaging and fun was the fundamental user experience goals that the project aimed to meet in order to trigger at least the low level levels of reflection (level 1 and 2). In general, based on the user rating (using a 7-point likert scale) on the museum experience, a high percentage of participants agreed that the game created an immersive museum experience (M=6.35; SD=0.71). User feedback also highlighted the positive museum experience as "creative,

enjoyable & informative" and "a good experience". The result of evaluation showed that level 1 and 2 reflections were achieved as there were many instances of participants being able to get the 'basic idea of culture' when the experience was made fun through gamification. For example, participant D1 remarked: ""I think it's really, really effective at making it fun. and getting most people at least a basic idea of culture." The participant also explained, "Because as a computer game, it was fun to remember." In another example, participant C1 also agreed that "The trading game was fun for the kids too. It's simple and straight forward but you get the idea". The game stations were found to be fun and engaging, which helped aid their learning about the culture. This conclusion can be further supported by evidence from participant A1 who stated "It definitely enriched my understanding of little things here and there, like the trading game."

2. Creating connection and meaning: The IoT serious game had a strong, positive effect on linking the past (history) with present through the use of artefact (both digital and physical), a key benefit of using the IoT approach, to create meaningful museum experience and to make connections with the Peranakan people and culture. The IoT approach enabled high level of user interaction through hands-on, physical 'making' and was often their favourite part of the experience based on feedback given by A2: "Actually my favourite is probably the Ang Gu Kueh, where you could grind it out" and F1: "Especially the food grinder where you get the chance to do your own food, get these games. It's just like everything is nice, get to explore." Another participant A1 reasoned that "I think different child learns differently and different adult learns differently. My son likes doing things with his hands". Thus having game stations that are more hands-on suit his learning, personalised style (according to his other parent A2). The connection with exhibits through hands-on learning was often linked to the reasons participants gave for becoming more aware of the culture, which experience even led some evidence of transformative and critical reflections, though the latter was lesser. For example, C1 felt that "it helps focus the children, learning and experiencing", while E1 also thought that "the interactive program helps to enhance the learning experience". There were also evidence of higher level of reflections being triggered through the user interactions. For example, A2 reported that "This time I became even more aware that different things in the house - different food, different decorations all come from all throughout the world and it's all mixed together in a very amazing way. And today's interactions help me become more aware of that".

3. Creating memorable experience: A number of participants reported that the game experience caused them to be interested and surprised to know new things about the Baba Nyonya culture and in a deeper way. The result of evaluation highlighted elements

of ‘surprise’, ‘process of inquiry’ and ‘satisfaction’, which can provide opportunities for reflective learning. For reflective game design, Khaled (2018). suggested that there are several game design qualities that could potentially facilitate critical reflection such as by introducing an element of surprise. Similarly, according to Baumer (2015), the role of ‘breakdowns’ involving moments of surprise, uncertainty, or conflict may (or may not) ultimately lead to transformative reflection. In addition, if players are to continue reflecting on their experience after play, these experiences must be memorable and ’stick’ with the player in some way as identified by Marsh and Costello (2013)’s notion of ‘lingering’. From the result of evaluation, it was shown the trading game play created moments of surprise for a family (A) that led to deeper understanding (transformative reflection) of the origin of culture, where A2 shared “*Last time very dangerous, so they can charge a lot more. So, when you just move things around us. Everyone realised, wow!.. So that was the little ‘wow’ moments”.* The family A went on to discuss the experience and engaged in critical reflection post-tour as they talked about why it is important to make profits in business and also ways to do business such as barter trade where no money is exchanged. In the post-tour conversation of another family F, their daughters (aged 6 and 8) “talked a lot about the kitchen: the setup, the contents, and especially the kueh maker”. F1 explained *“I think this resonates with something they really like to do – pretend play”.* This suggests that being engaged in an activity that gives players great satisfaction or pleasure will help them remember or talk about the experience more, which could lead to higher level of reflections. It is also worth noting that shared experiences in game play (as opposed to conventional individual game play) further encouraged group reflective discussion post-tour.

4. Revisiting the experience: The IoT serious game experience was deliberately designed to include many ways for players to revisit their experiences immediately at the end of the game play and post-tour through the use of physical and digital souvenirs. The game mechanic of collecting the souvenirs was used, which items became the game components needed for them to decorate their virtual house at the end of the experience. These souvenirs were also personalized e.g. photo of players wearing their self-made jewellery and hand-drawn lantern to hold a clear connection to the exhibits or game stations and represent the personal journey. Although, many players were more enthusiastic about souvenirs deemed to be more novel (e.g. Batu Boh capsule) and less keen on printed picture and photos taken of themselves, the effect of the personalized souvenirs in triggering reflection was not clear and conclusive in the evaluation study. At the same, the project expected participants would share their thoughts in the virtual house decoration game, as a feature to encourage reflection, but most participants (children) were shy to share their ideas. However, having observed the keenness of

players to continue engaging in the game, the personalized souvenir could extend the interaction into the future by offering online gameplay (as seen by a request from participant to download the trading game to continue play post-tour). What worked to help players get 'inducted' into the game experience was a pre-tour trading game station and having a post-tour virtual house to help players take a step back to revisit all the experiences (from room to room). One family G noted how her daughter learned about the concept of trading and began to use the concept in her daily life post-tour, an evident showing transformative reflection (G1: "I was surprised to hear my daughter starting to use the word "trade" in her daily conversation to initiate a trade of objects with her sister. She must have understood and internalized the concept". There were many instances that showed that transformative reflection could happen when visitors gained rich knowledge about the culture.

In conclusion, having evaluated the IoT serious game based on the reflection framework by Fleck and Fitzpatrick (2010), and in contrast to previous studies, the post-game interviews recorded evidence for all levels of reflection, with many examples of dialogic and transformative reflections. In the game design, the research developed a trading game as a pre-learning game to helps participants understand the origin of culture by connecting the past with present. The role-play game experience constructed an immersion learning experience for participants. These design elements with efforts to enhance engagement and meaning provided the foundation for low-level reflections, while the effort to create memorable experiences and through repetition (revisiting experience) suggest some success in supporting higher level of reflections.

6.2.3 Guideline for IoT Serious Game

As IoT serious games in museums are still relatively new, knowledge is lacking about how best to design and develop these games. Furthermore, IoT serious games for museums are more complex to develop than traditional digital games as they are closely coupled to the real-world museum context in which they are played. Based on the research experience of developing and evaluating the pilot and main museum studies, the project synthesises a set of guidelines to help future developers design IoT serious games in museums.

Guideline 1: Objects or artefact play an important role as game components in an IoT serious game. This valuable museum collection should be identified through cultural themes such as Music, Artwork, History, Customs and Traditions, Performance Art, Religion, Food, Artefact, Clothing, Religion, Recreation, Architectural design, Economic

System, Social Organisation and Language. At the start of the project, a lot of time were spent in the museum and communicating with the museum curators to get more understanding on possible museum themes with associated artefact to feature as part of the museum game experience. At this initial design stage, the team had to identify which artefact was suitable and of great value to highlight the uniqueness of the culture. For example, this project focused on the theme of Baba Nyonya food to highlight the rich history of spices which was connected to the origin of the culture. The project explored various existing artefact in the museum kitchen including an antique ice cream maker and stove and considered how the artefact or the kitchen environment (e.g. surrounding the stove) could be enhanced digitally or embedded with sensors while protecting the artefact from risk of damage. Future museum curators and developers will need to consider ways to embed sensors into artefact such as by creating replicas or augment an existing artefact digitally as part of the process of creating IoT serious games.

Guideline 2: Designing for reflection in museums is a big challenge and will need careful and detailed design considerations. So far, the reflection framework by Fleck and Fitzpatrick (2010), provided four levels reflection that could be triggered from low to high, for use within teaching and learning context. The project further refined the reflection framework based on the context of culture (see section 8.2.2). Similar museum projects should intentionally identify possible visitor engagement to include learning gains and levels of reflection goals to provide deeper visitor engagements and interactions with the cultural learning content and artefact. To achieve the different levels of reflection the research project further introduced seven design goals which were incorporated into the game storyboard and learning content. Future game design should identify the desirable level of visitor engagement and consider ways to achieve it by adopting or adapting the design goals used in the project as guideline.

Guideline 3: Future museum game developers will need to be aware that certain game genres are more suited to support reflective learning than others. For example, there are many serious games that impose a time limit on the game play. This element of game conflict in the form of time pressure will not be suitable for designing serious games within the museum context, especially if the engagement goal involves reflection. This is particularly important if we want the players to have time to ponder and reflection, whilst time limitation might disrupt their thoughts. In contrast, game genres such as role-play and simulation game as demonstrated through the museum studies here, will considerably help visitors understand the history and different aspects of a culture, for example, by putting themselves in the shoe of a Baba or Nyonya. At the same time, mission-based tasks such as having to solve puzzles from station to station can also

help players to see through multiple lenses or perspectives to provoke thoughts. For example, in the goldsmith station, players could choose and solder together various pendants and coins, which designs were from various influence e.g. Chitty, British, Chinese to help them learn about the fusion culture in subtle way.

Guideline 4: In the museum project, augmented artefact (e.g. Batu Boh, air pump at goldsmith station) and digitally enhanced artefact (e.g. antique lantern) were created to allow visitors to engage with these artefacts. Various physical input interaction techniques were supported through the use of various types of sensors to include RFID tag and IR sensor. For example, in the goldsmith station, an IR sensor was embedded into an antique air pump traditionally used by goldsmith to start a fire for soldering. This required players to step and press the air pump with their feet repeatedly until the 'virtual' fire light up to simulate the process of jewellery making like a goldsmith. In the Batu Boh station, the physical input of inserting ingredients and grinding them using the Batu Boh triggered the release of aromatic food smell to signal the success of 'kueh' making, followed by the physical output of the 'kueh' being rolled out to the player. In the design of future IoT serious games in museums, designers could consider novel ways of engaging visitors through the use of various input sensors and output actuators with creative use of sensorial media such as sound and graphics (e.g. projection onto artefact). The benefit of this approach is to maintain users' attention on the artefact and physical environment itself, rather than detracting them to focus on the technology itself (e.g. mobile screen). At the same time, designers will need to balance out action with reflection. The experience from the project was that too much of physical interaction, especially with simultaneous delivery of learning content (e.g. 'grinding' of ingredients while the audio narration played) would not yield favourable learning gain. However, when the task was redesigned to allow time for physical activity, then followed by time for listening and reflection, it worked far better. This suggests that designers should design for action intersperse with moments of slowness to make space for reflection (Hallnäs and Redström, 2001).

Guideline 5: IoT serious game technology provides opportunities to closely link physical and digital interactions. In turn, this provides new design space to connect the past with present. For example, the project presented the historical origin of the Peranakan culture through an online trading game and link it to the physical environment and artefact in the museum. The presentation of the cultural narrative through digital stories and augmented artefact provide multiple perspectives from the past and present, allowing visitors to understand and compare between old and new generations, and consider similarities and differences in terms of lifestyle e.g. food, economy and social. It is hoped that such

rich experiences will help trigger intergenerational conversations between the old and young visitors. For example, the Batu Boh was successful as supporting such conversations as the replica was based on a kitchen artefact widely used for Peranakan food preparation, and as players engaged in food 'grinding', they could hear conversations that re-enacted life in a busy Peranakan kitchen in the old times. The linking of past and present encourages visitors to reflect on their own family tradition and relationships. For example, there were instances where parents were observed to share their own experiences while growing up after their interaction with the Batu Boh.

Guideline 6: Future designers should consider possible issues related to implementing an IoT serious game within the context of a museum as it is different from more commonly implemented traditional mobile game or tangible exhibits in museums. For traditional mobile game, developers will need to focus only on the visitor flow and mobile game content, while for tangible exhibits, developers are mainly concerned with the standalone exhibit content and hardware design. As IoT serious game is considerably more extensive (e.g. to encompass multiple, connected exhibits) and spans both physical and digital, its design and development will need to consider many possible issues that could arise due to limitations in technology e.g. internet network connection and design challenges such as intergenerational gap to facilitate conversations between older and younger players.

Guideline 7: Future designers could consider implementing data-driven method to designing IoT serious game in museums. For example, sensor data sensed from the physical environment or artefact could be used to trigger a game output to provide enhanced game immersion. However, currently, most game development platform do not support integration with IoT sensor data. In contrast, most IoT development platform are available for home automation or industrial applications. As such, in order for more future designers to be able to create IoT serious game for museum applications, the data communication and sharing channel between IoT sensors and game development platform will need to be created. Therefore, one of the main contributions of the project, following the main museum study, is to overcome this challenge by introducing and developing an IoT toolkit for museums to allow museum teams to quickly brainstorm, build and test out their game ideas.

6.3 IoT Toolkit for Museum Innovation

Based on the lessons learned from the pilot and main museum studies, the project identified some main challenges of implementing the IoT approach with serious game,

namely: 1) lack of knowledge in IoT game ideation and design process among design teams and 2) missing IoT plugin to a game engine. The proposed guidelines for designing IoT serious game for museums as outlined in section 8.2.3 were translated into a set of IoT card game to help design teams generate ideas, while an IoT development kit was created to serve as an IoT plugin to a widely used and popular game platform, Unity3D. This section discusses the effectiveness of the IoT card game and development kit in supporting the design and development of IoT serious game among design teams.

6.3.1 Effectiveness of IoT Card Game

As IoT serious games for museums are more complex to develop than traditional digital games, the design patterns of the card game overcome this by providing guidelines in the specific domain knowledge to cover the entire design process from Asset cards to identify museum theme and learning content, to Engagement cards to design for visitor engagement game, and then to use Serious Games and IoT cards to add game elements and real-world interaction to improve level of visitor engagement and finally to use Possible Issue cards to refine generated ideas. Therefore, these guidelines are not only limited to game mechanics but also the museum design decisions and IoT systems (e.g. sensors, actuators). Over the course of two user studies, the research project observed how participants generated design ideas for IoT serious games, some of which were then prototyped. The card game has proven to be an effective tool for teams of designers to generate ideas in a short time. For example, in the user studies, participants were able to create unique design ideas within an hour of designated workshop duration. In the aspect of idea quality, most participants were satisfied with the quality of brainstormed ideas ($m = 3.6$; $sd = 0.71$ in first study and $m = 3.47$; $sd = 0.77$ in second study). This success can be attributed to the use of domain-specific design patterns as one of the characteristics of the cards and rules, which reduces development time and improves design idea quality.

Because IoT is a large and evolving computing concept, many designers – especially those without a technical background - find it hard to grasp IoT and understand how it works. In the card game, the research defines IoT as nothing but physical objects around us with embedded sensors and actuators, connected to the Internet. As one of the objectives of the card game is to help non-experts understand IoT, the research have simplified the IoT components to focus only on input and output to the users as a more intuitive way to create human-computer interfaces, while assuming the “hidden” aspects such as network connection is available for device communication in museums. The

initial user trial revealed that participants had a hard time understanding these components. In first version card game, the Technology card only had sensor or actuator name with very little information on the cards, which participants found challenging. Efforts were made to redesign the Technology cards by adding more description to educate participants on the various sensors and actuators that they can use and understand how they work. The new design of Technology cards received positive feedback from survey (m = 3.83, sd = 0.92 in first study and m = 4, sd = 0.66 in second study for Q14 in table 5.1). The results of interview also showed that the IoT cards were able to help participants understand IoT technology.

With regards to the question on creativity, most participants agreed that the card game helped them “think out of the box” (m = 3.88, sd = 0.92 in first study and m = 3.94, sd = 0.62 in second study for Q9 in table 5.1). This suggests that the card game can be used to foster creativity when creating something new, and ease planning and outlining of ideas. For example, when a participant draws an unfamiliar card, this helps him/her to think hard as to how to incorporate the card element into the overall design. To increase individual creativity and improve game play, the research also made changes to the game rule. In the first version of card game, every group would randomly draw a number of different type of cards and discuss them together. In the second version, every group member will now draw a card in turn and contribute his/her idea to the discussion. This change made the design process more fun as shown by the results of survey (m = 3.76, sd = 0.87 in first study and m = 3.89, sd = 0.74 in second study for Q4 in table 5.1). In addition, designers can identify potential risk before game development with the Possible Issue card, which results of survey show that it encouraged group discussion (m = 3.64, sd = 1.15 in first study and m = 3.95, sd = 0.78 in second study for Q16 in table 5.1) and helped participants identify problems that they never thought of (m = 3.6, sd = 1.11 in first study and m = 4.0, sd = 0.94 in second study for Q17 in table 5.1). In summary, the card game supports the core goals of typical pattern languages: Communication (discussion/collaboration), Analysis (representation/standardisation), Creativity (outlining/planning) and Improvement (problem solving/prevention) (Mora, Gianni and Divitini, 2017). The results of survey indicated some level of success in supporting these qualities.

An element of novelty compared to previous works in the card game is that it encourages designers to design for in-depth visitor engagement. This is not an easy task, due to the diversity and inter-disciplinary of the skills involved. The role of museums itself has changed over time from collecting, preserving and sharing rich collections to supporting community building, shaping cultural identity, enhancing social behaviours and so on

(Andermann and Arnold-de, 2012; Antoniou et al., 2013; Van et al., 2013). The card game addresses this need through Engagement cards, which suggest possible engagement goals. For example, designers may be challenged to design for deeper level of reflections to include transformative reflection (e.g. players explore new perspective) and critical reflection (e.g. players consider aspects wider than immediate content). A majority of participants agreed that the Engagement cards were useful for brainstorming (m = 3.48, sd = 0.91 in first study and m = 3.84, sd = 0.69 in second study for Q13 in table 5.1). Following the results presented, the IoT serious game card will be used as a teaching and learning tool in the HCI module teaching in the coming year.

6.3.2 The Potential of IoT Development Tool

IoT serious games have potential in creating deep visitor engagements in museums. However, the integration of IoT hardware (e.g. sensors and actuators), artefacts and game elements is a big challenge for software developers. Based on research into several existing IoT development toolkits, it was found that most of these toolkits were designed for creating IoT products (e.g. RapIoT, LittleBits). Since there is still a lack of IoT development kit that can integrate IoT data input and output, communication and sharing within a game development platform, the project proposed and developed an IoT game development toolkit that linked the Unity3D game development platform with Raspberry Pi environments. The main advantage of the IoT development kit is enabling developers to build IoT serious game without much IoT hardware knowledge, which will ultimately reduce the learning curve and development time.

The evaluation of the IoT development kit was conducted among the School of CS researchers and undergraduate students. The focus of the evaluation was to determine its usability and performance in reducing development time from current practice. The kit was designed with supporting instructions which proved to be clear and easy to follow as indicated by the result of user evaluation. It showed that most participants agreed that the instructions or guidelines for using different aspects of the kit (e.g. hardware, plugin) were easy to use and understand (Q1: m=4.36, sd=0.624; Q3: m=4.20, sd=0.70; Q5: m=4.20, sd=0.89). To optimize the performance of the development kit, the project focused on creating low latency of connection between the game client and IoT hardware. This was achieved through a real time communication structure. In comparison to RapIoT project, the project proposed an Arduino based toolkit to reduce the time to build IoT system but comprised of a complex setup structure and high latency in system design.

So far, the IoT system development usually involve a considerable amount of time to setup the data connection and transfer between software and hardware. Compared to current existing development practice, the IoT development kit provided an efficient way to develop game by helping users receive sensor data more efficiently and reduce the development time (Q7: m=4.12, sd=0.50; Q10: m=4.32, sd=0.67). In response to the question related to reducing development time, 44% of participants estimated that they would actually need more than 5 hours to finish a similar task without using the IoT development kit. Only 8% of participants thought that they could finish the same task in less than one hour. In the actual user trial, all participants managed to solve a specific task using Unity3D and requiring data communication between the game environment and IoT sensors in less than 30 minutes, an indication of success in meeting the performance goal of the IoT development kit. Furthermore, the introduction and use of the IoT development kit encouraged participants to develop more IoT serious game (Q2: m=3.84, sd=0.88).

The IoT development kit was provided as one of the prototyping platforms to be used in an HCI module for students to build their interactive installations. Initially, students would use the IoT card game developed in the project to brainstorm ideas and had the option of building the game with IoT development kit. Two out of the 6 student groups chose to use the kit to build their interactive prototypes. They were able to build them quickly and introduced support for physical user interactions (e.g. turning of wheel) rather than static prototypes as observed among other groups who did not use the kit. The IoT card game and IoT development kit when used together will provide an IoT serious game design and development solution package to educate and help design teams carry out brainstorming and prototyping activities with ease.

Chapter 7. Conclusion and Future Work

7.1 Conclusion

The role of museums is changing over time. Other than their traditional role of collecting, preserving and sharing rich collections, museums now play an increasing role in social communication and the development of communities such as to help shape cultural identity and support community building (Bampatzia et al., 2016). The opportunity for such informal learning that focuses on supporting visitor engagement in cultural learning and reflection has potential to contribute towards national unity, especially when so many countries throughout the world are ethnically and culturally diverse. Modern Malaysia is a young country that contains one of the most culturally diverse societies in the world, consisting of three major ethnic groups (Malays, Chinese and Indians) as well as many smaller groups. The culture of the Baba Nyonya represents this multiculturalism and fusion. The project worked closely with the Baba Nyonya Heritage Museum located in the old district of the World UNESCO area of Malacca town. The thesis reports the design and analysis of a museum visiting tour experience that was designed to facilitate inter-cultural and inter-generational dialogues about cultural identity in the museum.

Despite their value, museums struggle to stay relevant and keep their audience returning. Visitor studies have emphasised the need to increase engagement of museum visitors in different forms (Sandell and Janes, 2007). According to a constructivist approach, “museum exhibitions have to be designed and set up as an open work, providing different perspectives and viewpoints, to facilitate open-ended learning outcomes” (Simon, 2010). The role of new technology and the digital empowerment of museums have been considered crucial in attracting young generations and new audiences (Hughes and Moscardo, 2017). A pilot museum study was conducted with aim of designing and evaluating the effectiveness of IoT technologies in augmenting the visitor experience in a museum and cultural heritage context. The project design was based on the potential of IoT technologies, where two interactive exhibits, the goldsmith simulator and the Batu Boh were developed to enhance the kinaesthetic and multisensory experience of hands-on engagement with artefacts that are normally ‘hands-off’, in order to promote deeper engagement, discussion and reflection in small groups of visitors, especially children. The historical and cultural topics and learning content were chosen to highlight the rich diversity in the Peranakan culture (eastern and western influences, and different Peranakan ethnicities).

The result of pilot study presented some evidence that the experience resulted in significant learning gains in terms of knowledge of the content of the exhibits. Visitors liked the experience and felt that they had learned from it – in particular those aspects involving physical interaction. The qualitative analyses also showed instances of how the experiences enhanced discussion and sharing of Peranakan culture within the groups of visitors, especially intergenerational exchanges. In comparing between the different interaction techniques, it seemed that the Batu Boh exhibit of which involved a greater amount of physical engagement, was the more successful. These exhibits also afforded more collaborative interactions, where several members of the group could participate at once. These insights have been observed in other studies. However, where the project made an original contribution was in showing how relatively simple IoT techniques can create a rich inter-generational cultural learning experience, embedded in the original museum setting (rather than being separated from it) and that brings to life exhibits that are usually hands-off and experienced at a distance.

Having learned from the pilot study, a second user trial was conducted with the aim of extending the learning experience of visitors to further support reflection and social experience through serious games and IoT concepts. The popularity of video games, especially among younger people make them an ideal medium for educational purposes. Recent trends in the gaming industry are creating opportunities for Internet of Things (IoT) games. The technology becomes invisible, while the gaming experience becomes more immersive with increased richness of interaction. The digitalisation of works of art and historical artefacts using IoT further allows visitors to interact with either original or copies of cultural heritage artefacts physically, cognitively and emotionally using their senses. However, there is still limited research in this area as to how designers may combine both and design IoT serious games that will evoke deeper, cultural reflections to help shape community identity.

In order to achieve this project goal, the project adapted the reflection framework by Fleck and Fitzpatrick (2010) in the design and evaluation of the main museum study in order to achieve all levels of reflection. Seven design goals were incorporated into designing the main museum game experience which consisted of 5 interactive game stations to include: 1) an online trading game for visitors to learn the origin of the culture through the trading process 2) goldsmith simulator 3) Batu Boh simulator 4) lantern projection mapping and 5) virtual house decoration. The evaluation method employed surveys, interviews, video analysis and user observations. Through the survey feedback, the majority of participants agreed that the IoT serious game improved their experience during the tour with the Batu Boh exhibit interaction as the part of the experience that

they enjoyed the most. In addition, most of them felt surprised about receiving the Batu Boh souvenir (37.5%), being able to decorate virtual house (18.7%) and seeing the lantern projection (18.7%). In terms of discussions that they had with each other during the tour, many participants discussed about how things were made or done in the old days (44%), about their own childhood memories (33%) and the artefacts (22%). The pre/post-learning evaluation showed an increase in learning gains among adults (from 59.2% to 93.1%) and children (46.8% to 93.12%). However, a drawback to this study is that there was no control group to compare with any learning gains from visiting without the technology augmentation. Nonetheless, the results were encouraging.

Results from the interviews showed evidence for all levels of reflection to include higher levels of reflections where many transformative reflections and a few critical reflections were recorded. The results suggested that IoT serious game can provide an engaging museum visiting experience with a considerable high level of success in enhancing cultural learning and reflection. The design goals applied to the design process could be attributed to the success in achieving all levels of reflection. The project further discussed how reflection was facilitated by the IoT serious game, more specifically 1) in enhancing engagement, 2) creating connection and meaning, 3) creating memorable experience and 3) in supporting revisiting of experience. At the same time, some challenges of implementing IoT serious games had been identified with the main issues highlighting the difficulty with IoT game ideation and establishing communication between IoT sensors and virtual game.

As knowledge is still lacking as to how to design and develop IoT serious games for museums, the project synthesised a set of guidelines to help future developers design IoT serious games in museums. The design guidelines were further used to design and develop a card game solution with the following main objectives: 1) to improve idea generation efficiency of museum curators and game designers, 2) to help non-experts understand IoT technology and game design, and 3) to improve visitor engagement with valuable museum content and artefacts. The IoT card game consisted of 90 cards grouped in 5 categories for idea generation: Asset Card, Engagement Card, Serious Game Card, IoT Card and Possible Issue Card. Based on results of two user study workshops with undergraduate students, majoring in Computer Science, the card game was found to be useful in guiding non-experts in quickly generating ideas for IoT serious games.

In addition, previous development experience showed there is a gap between IoT hardware and game development where software developers need take long time to

build the communication between the game engine and IoT hardware. Therefore, we proposed IoT development kit for rapid IoT serious game development. The IoT development kit would solve the communication challenges between IoT sensors and Unity client. The integration of IoT card game and IoT development kit into an IoT toolkit has potential to support the design ideation and rapid prototyping of generated ideas to allow more IoT serious games to be introduced in museums.

7.2 Thesis Contributions

The main contributions of the thesis can be summarised as follows:

1. The design and development of prototype exhibit demonstrators in the form of augmented artefacts and smart replicas demonstrating how IoT technologies and serious game approach can be used in museums to encourage learning engagement as well as reflection of visitors.
2. Museum studies involving public trials in a real museum setting to suggest the effectiveness of IoT serious games in supporting cultural learning and reflection, and to reveal the benefits as well as challenges in the implementation.
3. The application and adaptation of the reflection framework by Fleck and Fitzpatrick (2010) in the evaluating different levels of reflection in museum and cultural context.
4. A set of guidelines for future designers to design future IoT serious games in museums.
5. An IoT toolkit to support the IoT game ideation through the introduction of IoT card game and an IoT development kit to connect IoT hardware with the game engine to reduce barrier to entry and the design and development time for future designers who wish to develop similar IoT game experience.

7.3 Dissemination

This section describes how the work reported in this thesis has been disseminated through paper submissions and publications:

The pilot museum project was first proposed with its results published in the following prestigious International Conference in Learning Sciences 2018 held in London, UK:

Hai, H., Lo, W.H., Ng, K.H., Brailsford, T. and O'Malley, C., 2018. Enhancing reflective learning experiences in museums through interactive installations. *Rethinking Learning in the Digital Age: Making the Learning Sciences Count Volume 2*, *2*, pp.776-783.

The work and results of the main museum study has been written in the following paper and submitted for consideration by an ISI-indexed journal, the Personal Ubiquitous Computing journal, a top journal in the field of HCI:

Hai, H., Ng, K.H., Lo, W.H. and Brailsford, T. An IoT approach to designing serious game in museums

The design, development and evaluation of the IoT card game has been written and submitted to the Journal of Ambient Intelligence and Humanized Computing, an ISI-indexed journal:

Hai, H., Ng, K.H., Bedwell, B. and Benford, S. A Card-based Internet of Things Game Ideation Tool for Museums.

7.4 Future work

This section describes proposals for future work to extend and refine the research described in this thesis.

7.4.1 Future IoT Game Development

While IoT development kit provides a rapid way for IoT game development, the implementation of IoT serious game still has many limitations. Many studies have started to apply Extend Reality (XR) technologies in the game area to increase game immersion experience. However, the current XR application is restricted by its hardware size, connection speed and computing power. Along with the development of 5G technology, it provides possibility to enhance the performance of XR game experience. This section will discuss the future development of IoT development Kit in 5G generation.

Future gaming trend will involve more development of XR games in open spaces. The high-speed capabilities of data streaming technologies and wireless networks have been integrated with XR for a long time (Orlosky et al., 2017). However, the performance of XR device was limited on its connection range, interactive ways, weight and computing power. Fortunately, both researchers and engineers began to realise how 5G networks

can help XR to build next generation of virtual interfaces. Along with the development of 5G network, the faster bandwidth and low latency internet connection provides many possibilities for XR game development and IoT development kit. The IoT development kit has the potential as a tool to support XR gaming experience in 5G generation. Future work could include several implementations of IoT development kit to support XR project in 5G generation:

- IoT sensors as new interaction method: The current XR games are mainly played in virtual worlds through controllers or motion detectors. In the 5G generation, IoT sensors can provide a new approach for XR interaction. The IoT sensors can be embedded into the physical environment and players can interact through sensor data, such as to trigger fire effect using pressure sensor.
- Multiple location game experience: The IoT development kit shows potential to support multiple location game experience. The IoT devices can be embedded into physical environments in different locations. During the game, two players can interact through the IoT sensor network. The IoT sensor network can be used to trigger effect or physical output on other game clients.
- AI + IoT: Recently, cutting edge computing involves integrating artificial intelligence (AI) to IoT device (Zou et al., 2019). The integration of IoT development kit and AI provides “thinking ability” to IoT sensors. The IoT devices can trigger different input or output through AI model in Raspberry Pi.

In conclusion, the IoT development kit shows potential to support XR game development in 5G generation. For the future development of IoT development Kit, it aims to develop more sensors to create a multisensory XR game in the physical environment.

7.4.2 IoT Platform

While the IoT development kit was developed as a toolkit to solve the communication issue between IoT sensors and Unity game engine, the back-end server was maintained and supported by the research team. In order to create a sustainable long term server hosting of the IoT development kit, the project proposes two possible methods for the implementation of future IoT development kit either using a Docker version IoT server or PaaS.

Previously, the deployment of server applications is a big challenge for engineers. The different machine environments come with different version software. Engineers may

need to take a long time to deploy a server. The concept of container technology proposed a way to develop, deploy and run the application inside containers. Engineers only need a few lines to deploy an application to server. Docker is one of the bigger container platforms that allows a back-end server to be converted to a Docker version. The source code of back-end server can be shared on GitHub.

Platform as a service (PaaS) offers a development platform that hosts both completed and in-progress cloud applications (Dillon et al., 2010). With the help of PaaS platform, developers only need to register an account on platform. In contrast to Docker, PaaS platform provides better support and maintainability for users. Future version of IoT development kit aims to explore an approach to launch IoT sensors through web applications. PaaS solution provides a better option for the IoT development kit.

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Appendix A: Post-test Form (Pilot Project)

Tag ID:

Feedback Survey for Interactive Exhibits

Please feedback your experience of interacting with the exhibits so that we can fully understand its potential, the challenges involved in the interaction and make it even better!

Section 1: Learning Outcomes

1. Which one of these is not part of the Peranakan communities?

A. Indonesian B. Peranakan Chitty C. Peranakan Chinese D. Baba-Nyonya

2. What does Peranakan means?

A. “Orginal tribe” B. “A Family of Children” C. ”Generations to come” D. ”Child of the land”

3. How to do the rich Peranakan clients get their jewlry made? A. Visit a goldsmith shop B. Commission goldsmith to come to them C. Make them themselves D. Buys them off dealers

4.Which one of these precious metals is often used to make Peranakan jewelry? A. Sliver B. Iron C. Pewter D. Steel

5.What is the purpose of Batu Boh?

As a…

A. Food Grinder

B. Ice Maker

C. Rice Cooker

D. Clothes washer

6.What is the use of a billows?

A. Starting a fire powered by coal

B. Pump high pressures air to blow away impurities surrounding pendant

C. Pump air to provide sufficient air flow for blowtorch

D. Pump water to cool down soldered pendant

7.What is the biggest trade industry in 500

years ago? A. Oil
B. Spices C.
Silk
D. Tea

8.”Kueh” is belong to which item in Peranakan culture?
A. Cloths B. Food C.Architecture D.Religion
9. Which kind of food is often prepared and eaten by the Peranakan Chitty community? A. Asam Laksa B.Bak Chang C.Sugee
Cake D.lepak Kacang

10. Which one of the following ingredients is most used in making Peranakan kueh? A.pendan B.Rice Flour C.Green
Beans D.Palm Sugar

Section 2: Usability

Please rate the following statements (1- strongly disagree to 7-strongly agree)

interactive exhibit	Goldsmith	Interactive poster	Batu Boh
The interfaces is logically designed with good flow of actions:	1 ☐☐☐☐☐☐☐ 7	1 ☐☐☐☐☐☐☐ 7	1 ☐☐☐☐☐☐☐ 7
The functions embedded in the exhibits are well integrated into each other :	1 ☐☐☐☐☐☐☐ 7	1 ☐☐☐☐☐☐☐ 7	1 ☐☐☐☐☐☐☐ 7
The design aspect of the exhibits meets my expectations :	1 ☐☐☐☐☐☐☐ 7	1 ☐☐☐☐☐☐☐ 7	1 ☐☐☐☐☐☐☐ 7
The actions required were rather obvious to me :	1 ☐☐☐☐☐☐☐ 7	1 ☐☐☐☐☐☐☐ 7	1 ☐☐☐☐☐☐☐ 7

Section 3: Comparison study

Please rate the following statements (1- strongly disagree to 7-strongly agree)

interactive exhibit	Goldsmith	Interactive poster	Batu Boh
The exhibit provides a good learning experience of the Baba Nyonya culture.	1 7	1 7	1 7
The exhibit encourages discussions with others	1 7	1 7	1 7
The exhibit helps me reflect/think more about my own culture	1 7	1 7	1 7
The exhibit wants me to learn more about the Baba Nyonya culture	1 7	1 7	1 7
The physical interaction with the exhibit enhances my learning experience.	1 7	1 7	1 7
I felt that I have gained more knowledge after using the exhibit.	1 7	1 7	1 7

Section 4: The experience

How did you feel about using the exhibits and what challenges you faced?

Which part of the experience did you enjoy the most?

What other feedback and recommendations do you have to improve the experience?

Thank you!

Appendix B: Pre-test Form (Pilot Project)

TagID:

Baba Nyonya Heritage Museum's Self-Guided Tour Survey

1. What's your gender?
   Male
   Female

2. What is your age group?
   [ ]

3. Are you tourist or local resident?
   Male Female

4. What is your current employ status?
   Student
   Home maker
   Employed
   Self-employed
   Seeking employment
   Retired
   Other

5. What is the highest level of education that you have completed?
   Less than high school
   High school
   College certificate/ diploma
   Bachelor's degree
   Master's degree
   Ph.D degree

6. If you have children, what is their age groups()?
   0-4 years
   5-9 years
   10-14 years
   15-19 years
   Not applicable

7. What is town or city do you live in?
   [ ]

8. Have you visited Baba Nyonya Heritage Museum before?

   Yes

   No

Please read the following statements and select “True” or “False”. If you are unsure of the answers, leave it blank.

	True	**False**
1. There are many different types of Peranakan communities.		
2. Peranakan means “A family of children”.		
3. Chinese goldsmiths were often commissioned by their rich clients to make special jewelry ornaments which became family heirlooms.		
4. Silver coins were often used as part of the Nyonya jewelry.		
5. Batu Boh is an equipment used to create ice in a typical Peranakan’s kitchen.		
6. A billow is used to pump air into the blowtorch for soldering.		
7. Spices was the world’s biggest industry 500 years ago.		
8. “Kueh” is a type of food originating from the Indian culture.		
9. “Sugee Cake” is a delicacy from India.		

10. “Rice flour” is one of the most used ingredients in making Peranakan cakes and dessert.		

Appendix C: Pre-test Form (IoT Serious Game)

Baba Nyonya Heritage Museum's Self-Guided Tour Survey

1. What's your gender?
   Male
   Female

2. What is your age?
   [ ]

3. Are you tourist or local resident?
   Male Female

4. What is your current employment status?
   Student
   Home maker
   Employed
   Self-employed
   Seeking employment
   Retired
   Other

5. What is the highest level of education that you have completed?
   Less than high school
   High school
   College certificate/ diploma
   Bachelor's degree
   Master's degree
   Ph.D degree

6. If you have children, what is their age groups()?
   0-4 years
   5-9 years
   10-14 years
   15-19 years
   Not applicable

7. What is town or city do you live in?
   [ ]

8. Have you visited Baba Nyonya Heritage Museum before?
   Yes
   No

Your Tag ID No

Please read the following statements and select "True" or "False". If you are unsure of the answers, leave it blank.

	True	False
1. Malacca was not a major port along the spice route.		
2. Peranakan Chinese means "A family of children".		
3. Chinese goldsmiths were often commissioned by their rich clients to make special jewelry ornaments which became family heirlooms.		
4. Hand painted lanterns were placed outside the house to show house number.		
5. Batu Boh is an equipment used to create ice in a typical Peranakan's kitchen.		
6. A billow is used to pump air into the blowtorch for soldering.		
7. Spices was the world's biggest industry 500 years ago.		
8. Traders bearing tea, cotton and black pepper from China came to Malacca to exchange for spices.		
9. "Sugee Cake" is a delicacy from India.		
10. "Rice flour" is one of the most used ingredients in making Peranakan cakes and dessert.		

Appendix D: Post-test Form (IoT serious game)

TagID:

Feedback Survey for Self-Guided Tour

Please feedback your tour so that we make it even better!

Section 1: Learning Outcomes

1. In the 20th century, the following traders were sailing to Malacca from the following countries, except from: **A.** China **B.** Great Britain **C.** India **D.** Korea

2. What does Peranakan Chinese means?
A. "Original tribe" **B.** Tourists from China **C**. Businessmen from China **D.** Descendants of Chinese immigrants who married the locals

3. Select the origin of the coins used in making a Peranakan pendant. **A.** India **B.** Portugal **C.** United Kingdom (UK) **D.** China

4. What was placed outside each Peranakan house for families to show who the house belonged to? **A,** Bicycle **B.** Lanterns **C**. Chairs **D**. Bonsai plants

5. What is the use of a Batu Boh?

As a..
A. Food grinder
B. Ice maker
C. Rice Cooker
D. Wash cloth

6. What is the use of a billow?
A. For cleaning the jewelry
B. Pump high pressured air to blow away impurities surrounding pendant
C. Pump air to provide sufficient air flow for blowtorch
D. Pump water to cool down soldered pendant

7.What is the biggest trade industry in the world 500 years ago? **A**. Oil **B**. Spices **C**. Silk **D**. Tea

8. Which of the following item from India were traded in Malacca?
A. Cloths **B.** Tea **C.** Chocolate **D**. Salt

9.Which kind of food is often prepared and eaten by the Peranakan Chitty community? **A.** Asam Laksa **B**. , Bak Chang **C**. Sugee Cake **D**. Lepak Kacang

10. Which one of the following ingredients is most often used in making Peranakan Kueh?
A. Pandan **B.** Rice Flour **C.** Green Beans **D.** Palm Sugar

Your Tag ID No

Section 2: Feedback on tour

Please rate the following statements. (1 = low, 7 = high)	1	2	3	4	5	6	7
1. The trading game added to the enjoyment of the tour.							
2. The trading game helps me learn more about the Peranakan history.							
3. The physical interaction with interactive exhibits enhances my learning experience.							
4. The game creates an immersive museum experience.							

Section 3: The experience

Which part of the experience did you enjoy the most?

Which part of the experience that surprised you the most?

What discussions did you have with each other during the tour? Did you share a personal story?

Do you have any new understanding of Peranakan culture after the tour? If yes, please share here.

Appendix E: IoT Toolkit Survey

Unity3D plugin survey

1. What is your gender?

€ Male

€ Female

2. What is the highest level of education that you have completed?

€ High School

€ Diploma

€ Degree

€ Masters

€ PhD

3. On a scale of 1 to 10, how do you estimate your programming experience?

1: Very inexperienced 10: Very experienced

€ € € € € € € € € €

4. How experienced are you with the following development tool: Unity3D

Very inexperienced Very experienced

€ € € € € € € € € €

5. How experienced are you with the following development tool: Raspberry Pi

Very inexperienced Very experienced

€ € € € € € € € € €

Experience

Please rate the following statements. (1 = Strongly agree, 2 = Agree, 3 Neither agree nor disagree, 4 = Disagree 5 = Strongly disagree)

Question	1	2	3	4	5
1. The hardware instruction is easy to understand.					
2. The IoT toolkit inspire me to develop mixed reality game					
3. The Unity3D plugin document is easy to understand.					

4. The IoT toolkit gives me confidence to create more mixed reality game.					

Question	1	2	3	4	5
5. I can easily setup sensors with Raspberry Pi with toolkit instruction.					
6. I can easily activate sensors with python script.					
7. Unity3D plugin helps me receive sensor data more efficiently.					
8. The code of Unity3D plugin is easy to access.					
9. If you were to program the same game without IoT toolkit, how long do you estimate to finish?					
10. The IoT toolkit reduce the development time.					

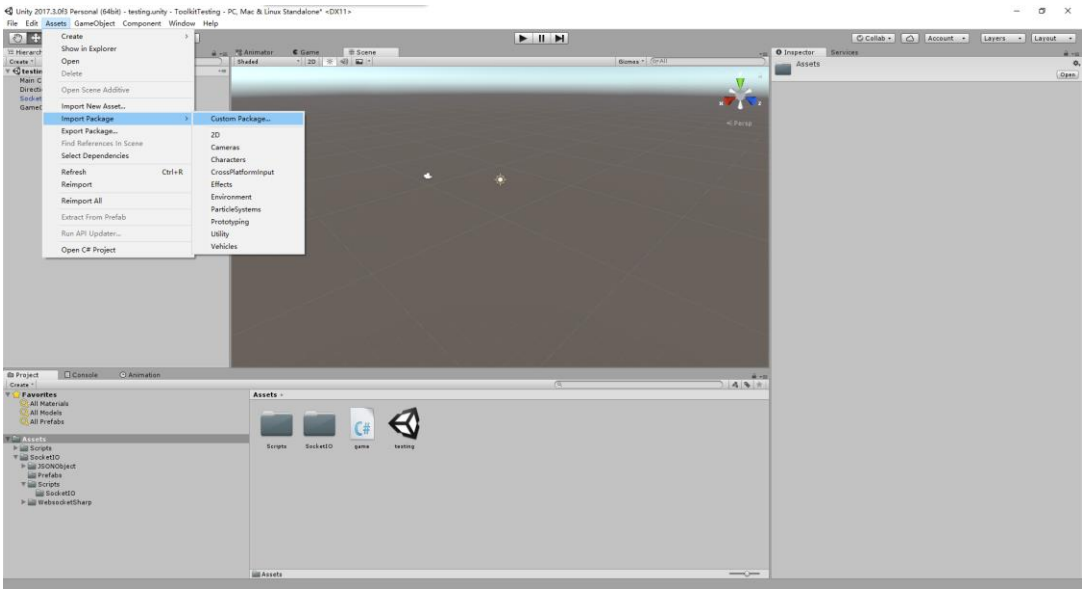
Feedback

1. Do you have any suggestion for improving the IoT toolkit?

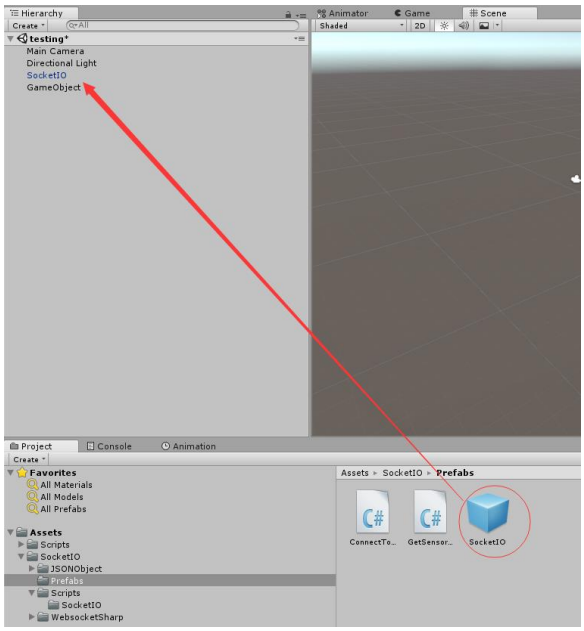
Appendix F: Instruction for Development Kit

Unity3D plugin example

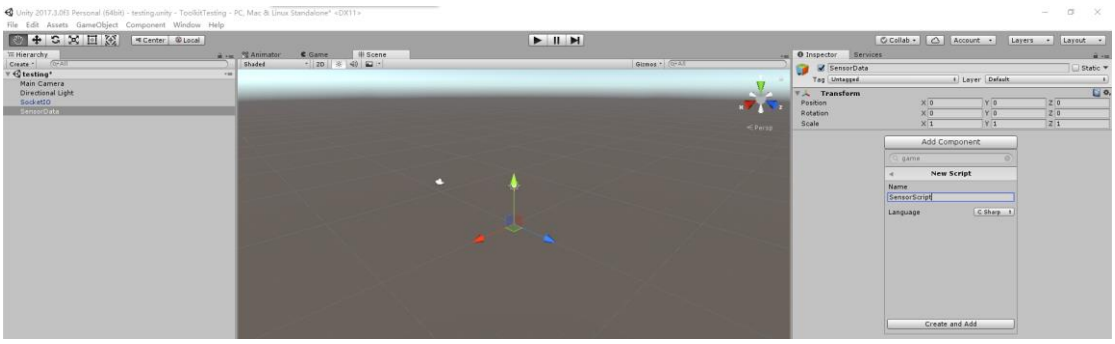
1. Import “Socket.IO” package to Unity3D.



2. Open folder “SocketIO/Prefabs”” then drag and drop “SocketIO” to hierarchy



3. Create a empty game object and empty script. Name it “SensorData” and “SensorScript”. Attach “SensorScript” to “SensorData”.



“4. Open “SensorScript” and getting data with following code

```
using System.Collections;
using System.Collections.Generic;
using Unity3DEngine;

public class SensorScript : MonoBehaviour {
   public GameObject Sensor;
        // Use this for initialization
        void Start () {

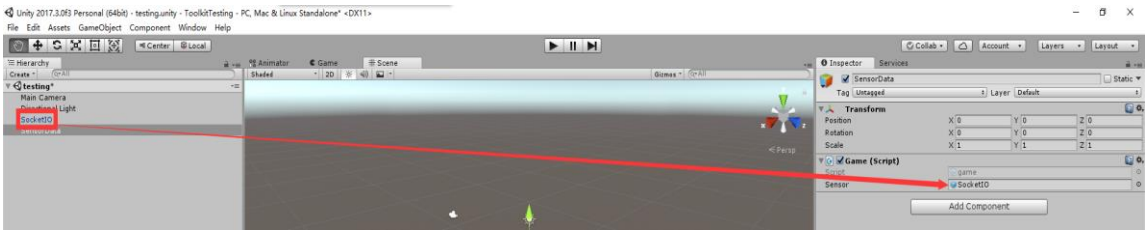
        }

        // Update is called once per frame
        void Update () {
      Debug.Log(Sensor.GetComponent<ConnectToServer>().SensorData.ToString());
        }
}
```

You can access sensor data by following code:

Sensor.GetComponent<ConnectToServer>().SensorData.ToString()

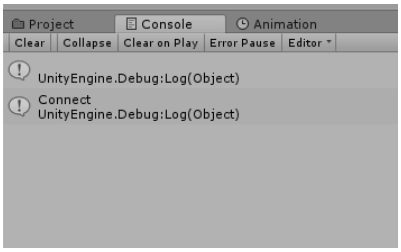
5.Drag and Drop “ScoketIO” to “GameScript”.

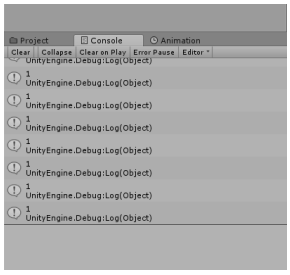


6. Play the scene.

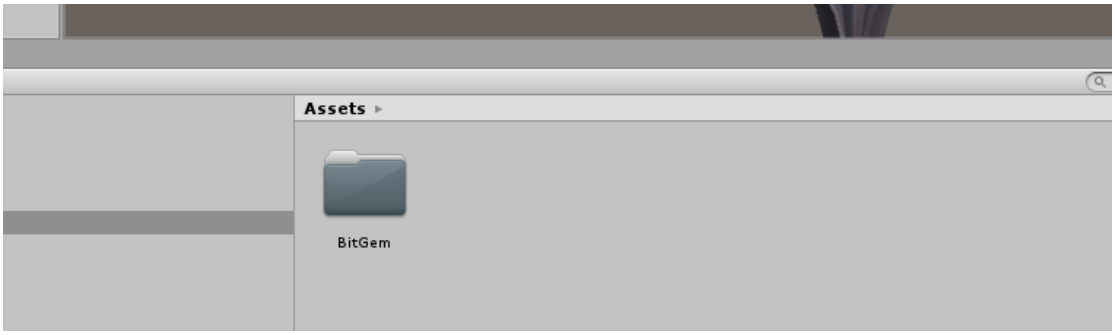
6.1 if you using touch sensor, try to touch different pins from touchboard. You will see sensor data from console.

6.2 if you using RFID, try to tap the card. You will see card id from console.

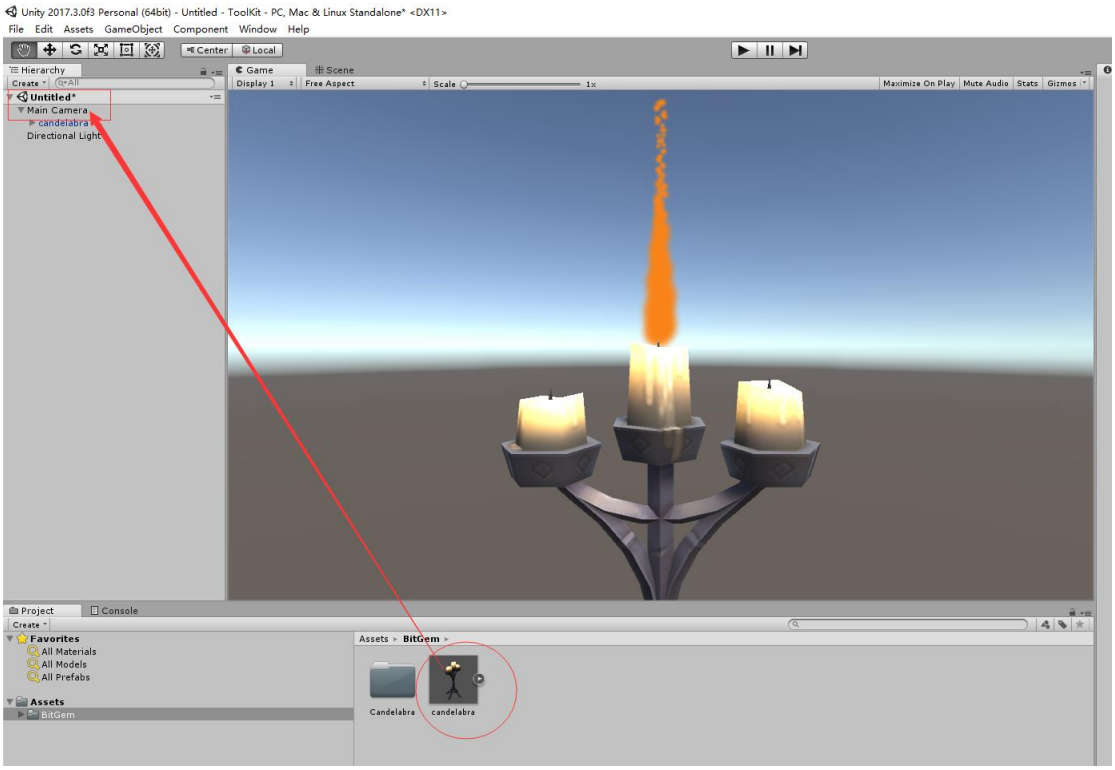




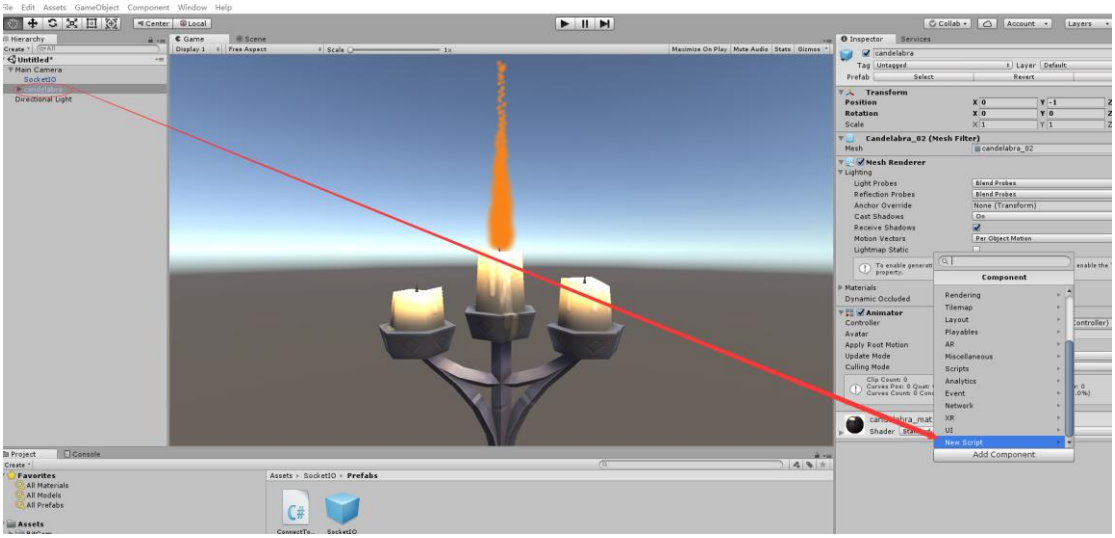
7. Import “**Candle**” package



8. Open **BitGem** folder. Drag and Drop “**candelabra**” to hierarchy.



9. Add a new script “FireControl” to **candelabra.**



10.edit **FireControl** script

```
using System.Collections;
using System.Collections.Generic;
using Unity3DEngine;

public class FireControl : MonoBehaviour {

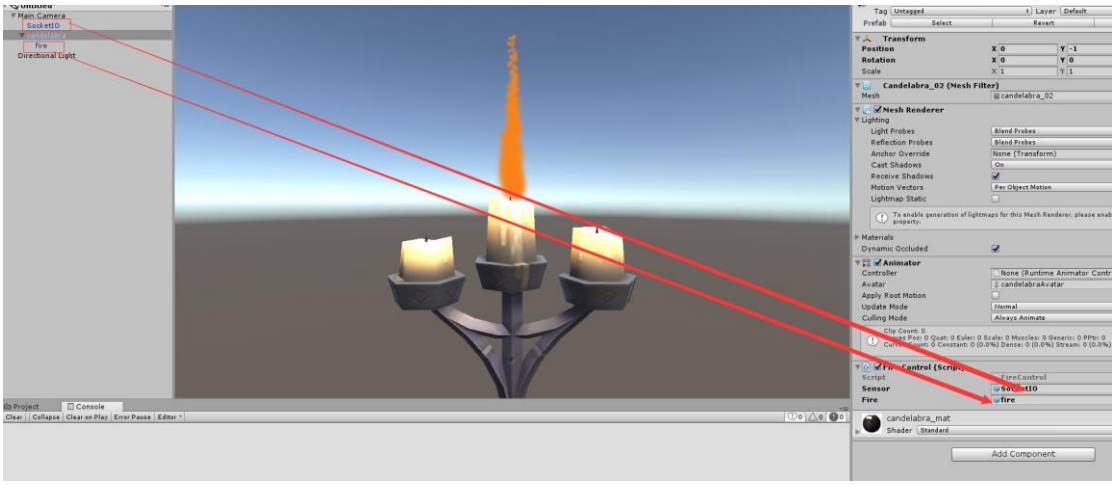
   // Use this for initialization
   public GameObject Sensor;
   public GameObject fire;
         void Start () {

         }

         // Update is called once per frame
         void Update () {
      //If touch pin 0, the fire will be disappear
      if (Sensor.GetComponent<ConnectToServer>().SensorData == "0")
      {
         fire.SetActive(false);
      }
      //If touch pin 1, the fire will be show
      else if (Sensor.GetComponent<ConnectToServer>().SensorData == "1")
      {
         fire.SetActive(true);
```

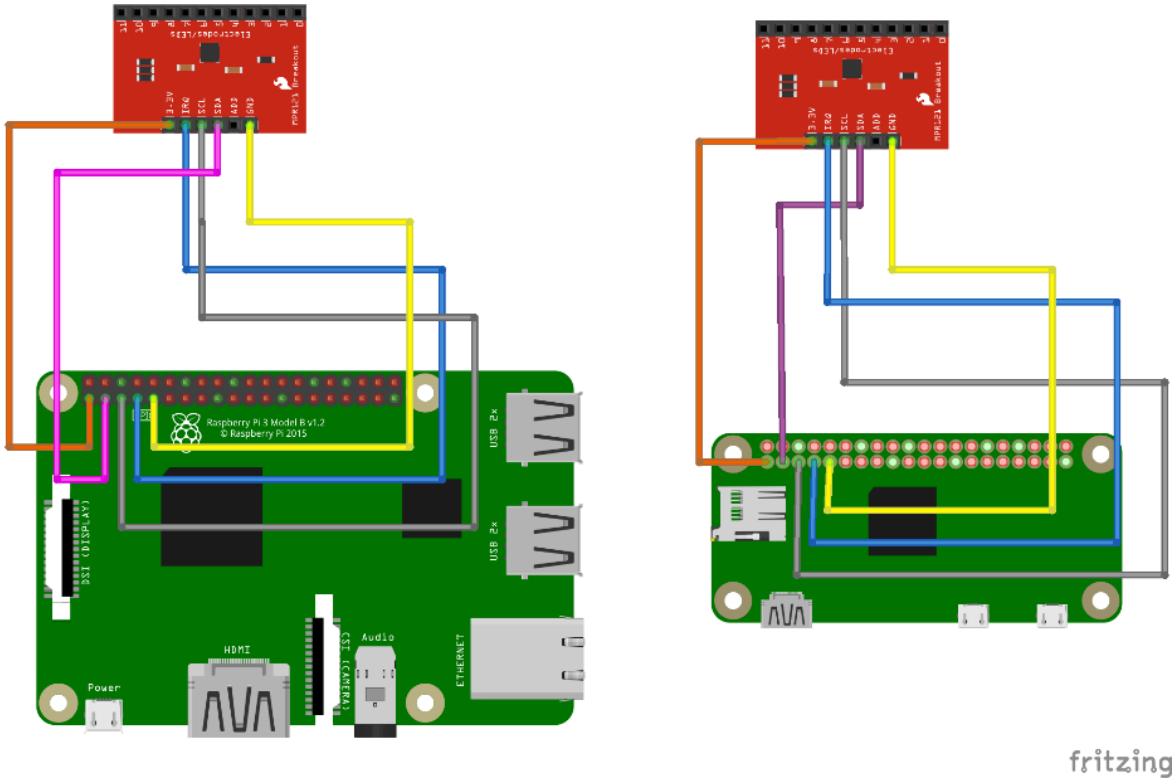
```
    }
  }
}
```

11.Drag and Drop **socketIO** and **fire** components to script. Play the scene and try to use touch sensor to control fire.

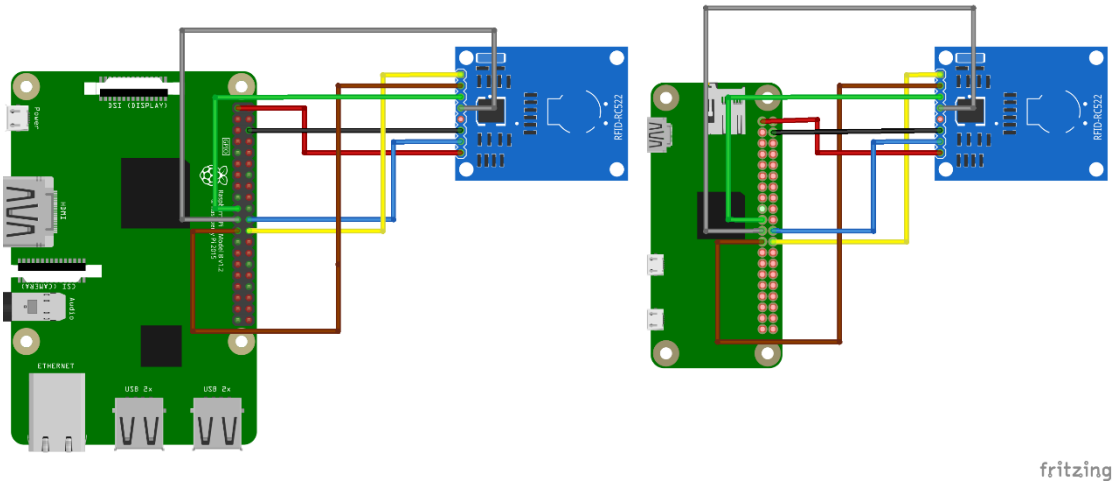


Raspberry Pi client setup

1. Connect Raspberry Pi and touch sensor like following diagram.



Touch Sensor



RFID

Raspberry Pi example

1. Open terminal from desktop, Enter “cd ToolkitV1” then enter “**sudo python Sensor.Py**”

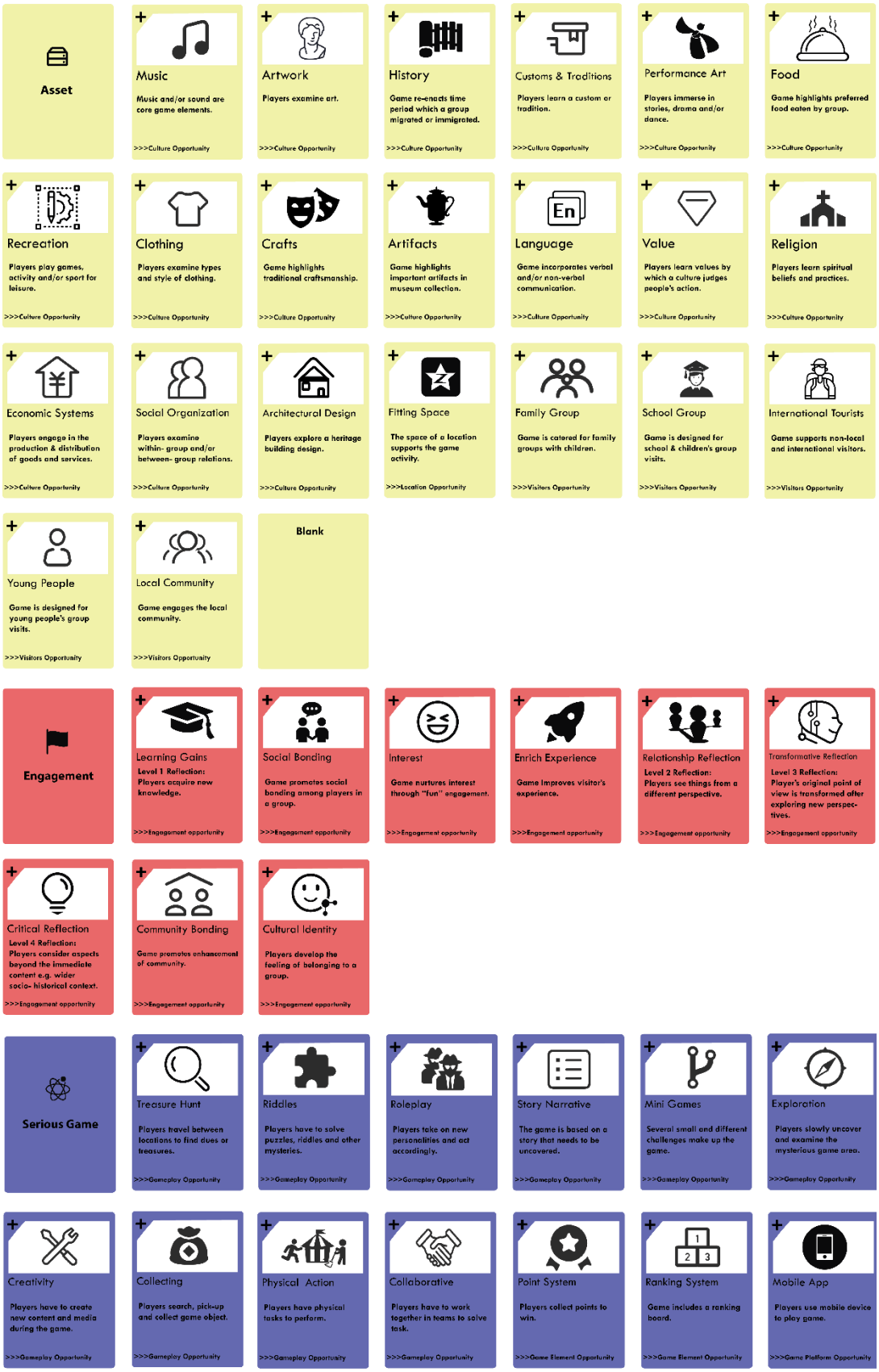
```
D:\>python Sensor.py
```

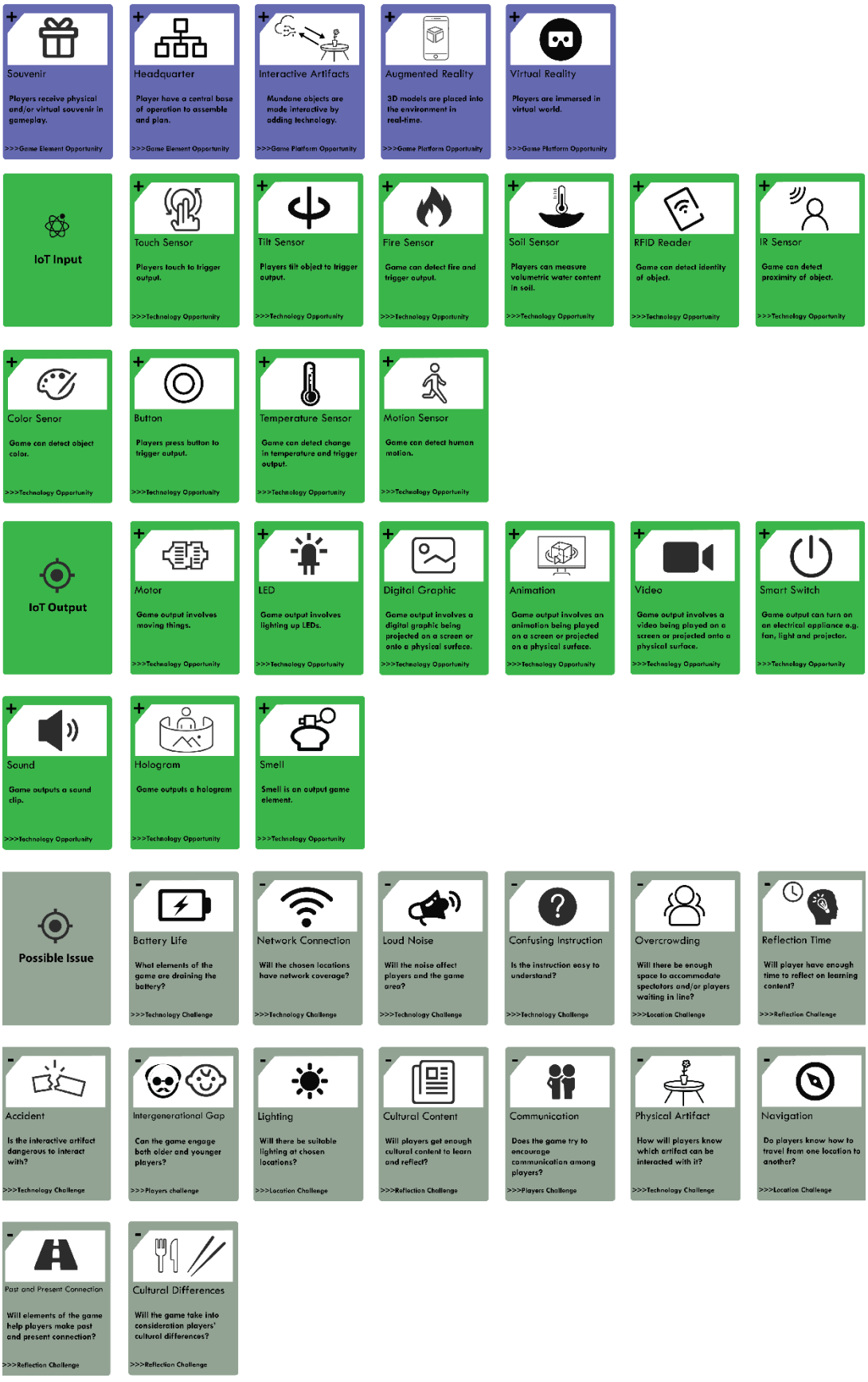
2. Select Sensor number

```
1. Touch Sensor
2.IR sensor
3.Motor
4.Tilt Sensor
5.RFID
Pleae insert sensor number:1
touch sensor
```

3. Done

Appendix G: Final Design of Card Game




Souvenir
Players receive physical and/or virtual souvenir in gameplay.
>>>Game Element Opportunity
Headquarter
Player have a central base of operation to assemble and plan.
>>>Game Element Opportunity
Interactive Artifacts
Mundane objects are made interactive by adding technology.
>>>Game Platform Opportunity
Augmented Reality
3D models are placed into the environment in real-time.
>>>Game Platform Opportunity
Virtual Reality
Players are immersed in virtual world.
>>>Game Platform Opportunity
IoT Input
Touch Sensor
Players touch to trigger output.
>>>Technology Opportunity
Tilt Sensor
Players tilt object to trigger output.
>>>Technology Opportunity
Fire Sensor
Game can detect fire and trigger output.
>>>Technology Opportunity
Soil Sensor
Players can measure volumetric water content in soil.
>>>Technology Opportunity
RFID Reader
Game can detect identity of object.
>>>Technology Opportunity
IR Sensor
Game can detect proximity of object.
>>>Technology Opportunity
Color Senor
Game can detect object color.
>>>Technology Opportunity
Button
Players press button to trigger output.
>>>Technology Opportunity
Temperature Sensor
Game can detect change in temperature and trigger output.
>>>Technology Opportunity
Motion Sensor
Game can detect human motion.
>>>Technology Opportunity
IoT Output
Motor
Game output involves moving things.
>>>Technology Opportunity
LED
Game output involves lighting up LEDs.
>>>Technology Opportunity
Digital Graphic
Game output involves a digital graphic being projected on a screen or onto a physical surface.
>>>Technology Opportunity
Animation
Game output involves an animation being played on a screen or projected on a physical surface.
>>>Technology Opportunity
Video
Game output involves a video being played on a screen or projected onto a physical surface.
>>>Technology Opportunity
Smart Switch
Game output can turn on an electrical appliance e.g. fan, light and projector.
>>>Technology Opportunity
Sound
Game outputs a sound clip.
>>>Technology Opportunity
Hologram
Game outputs a hologram
>>>Technology Opportunity
Smell
Smell is an output game element.
>>>Technology Opportunity
Possible Issue
Battery Life
What elements of the game are draining the battery?
>>>Technology Challenge
Network Connection
Will the chosen locations have network coverage?
>>>Technology Challenge
Loud Noise
Will the noise affect players and the game area?
>>>Technology Challenge
Confusing Instruction
Is the instruction easy to understand?
>>>Technology Challenge
Overcrowding
Will there be enough space to accommodate spectators and/or players waiting in line?
>>>Location Challenge
Reflection Time
Will player have enough time to reflect on learning content?
>>>Reflection Challenge
Accident
Is the interactive artifact dangerous to interact with?
>>>Technology Challenge
Intergenerational Gap
Can the game engage both older and younger players?
>>>Players challenge
Lighting
Will there be suitable lighting at chosen locations?
>>>Location Challenge
Cultural Content
Will players get enough cultural content to learn and reflect?
>>>Reflection Challenge
Communication
Does the game try to encourage communication among players?
>>>Players Challenge
Physical Artifact
How will players know which artifact can be interacted with it?
>>>Technology Challenge
Navigation
Do players know how to travel from one location to another?
>>>Location Challenge
Past and Present Connection
Will elements of the game help players make past and present connection?
>>>Reflection Challenge
Cultural Differences
Will the game take into consideration players' cultural differences?
>>>Reflection Challenge