CRANFIELD UNIVERSITY

Yijing Ji

An Agent-Based Model for Improving Museum Design to Enhance Visitor Experience

PhD in Design

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SCHOOL OF WATER, ENERGY AND ENVIROMENT

Academic Year: 2019 - 2022

Supervisor: Dr. Trung Hieu Tran

Associate Supervisors: Dr. Jude Simon; Prof. Leon Williams

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This thesis is submitted in partial fulfilment of the requirements for the degree of Philosophy

ABSTRACT

Museum experience is a multi-layered journey including ontological, sensory, intellectual, aesthetic, and social aspects. In recent years, the museum sector has faced a number of challenges in terms of the need to enhance the potential of the experience while maintaining authenticity and credibility. For public science communication in museums, exhibition is an important medium for connecting exhibits and visitors, and as such, the study of visitors' senses and behaviours under impact of various museum layout designs has become an important research direction.

The purpose of this study is to explore the recall of visitors' memories in the exhibition space by integrating images, echoes and tactile senses, and then transform memories and interactions into their own experience and knowledge base. The impact of spatial design and other design elements on visitors' memories is also explored. We have conducted Agent-based simulation, by setting up virtual visitors, exhibition spaces and artefact based on real gallery spaces, as a time-saving and cost-saving method to improve exhibition interactivity and content coherence. Meanwhile, through the simulation of this novel way, visitors can observe and predict the interactive experience between visitors and the exhibition, so as to improve the curatorial team's research on tourist behaviour and spatial design scheme. Next, the simulated data on visitors' memory recall behaviour is compared with the actual observed data to explore the authenticity of visitors' behaviour in the simulated museum. The impact of this study is by integrating a variety of shared understandings between curators, exhibition management and participants, drawing on diverse information based on experience, practice and simulation. It seeks to provide future museum-oriented practitioners, particularly in small and medium-sized museum exhibition spaces, with a novel perspective and approach to observing or predicting the experience of visitors' sensory interactions within an exhibition. Furthermore, at the same time as enhancing the visitor’s exhibition experience, the content of exhibition story is fully transformed into its own knowledge accumulation.

Keywords:

Cognition, Human Behaviour, Museum Space, Exhibition Space, Short-Term Memory, Interior Design, Sensory Experience

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It has been a difficult learning journey and I am finally in the final stages of my PhD journal. The most important lesson I have learnt along the way is that knowledge has no boundaries, we should always be curious and humble about the world. And we must learn to be thankful and grateful for the kindness given by everyone.

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STM	Short-Term Memory
LTM	Long-Term Memory
MVR	Memory Value Requirement
MVC	Memory Value Capability

1. INTRODUCTION

1.1 Background

1.1.1 Visitor Interaction in Museum Space

Museums are highly esteemed by society as places of national significance; their sizes vary, and they house some of the most historically significant artefacts in the world. However, the purpose of physical museum spaces to collect, protect, research, communicate, and exhibit materials for research, education, and entertainment is challenged as we enter the digital age (Ahmad et al., 2014). For example, do physical museum spaces play a crucial role in the future exhibition of priceless artworks, historical artefacts, collections, and objects with educational and cultural significance? Furthermore, can online digital experiences supplant more conventional visitor experiences? To address these issues, we discuss the significance of multisensory experiences in museum settings and debate whether they will become the economic culture's central competitive core (Wang & Xia, 2019).

Museum design and evaluation practice are increasingly centred on the visitor experience. A gratifying museum layout can provide a pleasurable experience for audiences from different cultural backgrounds (Falk & Dierking, 2016). Goulding (2000) discussed how the perception of exhibit information is relatively passive in many traditional museums. Visitors can only view exhibits from a safe distance, as there is no essential guidance or information linking the exhibit to other narratives associated with the museum's collection (Roberts, 1997; Packer & Ballantyne, 2002). Researchers have examined the dynamics of communication between humans and exhibition spaces, arguing that interaction is an effective way to engage visitors and allow them to absorb information in art, history, and cultural museums, among others (Allen & Gutwill, 2005). According to De Rojas and Camarero (2008), "museums that put collections/exhibitions and visitor experiences on an equal footing" are the defining characteristic of future museums. Interaction is crucial for humans. Traditional and sensory interactions influence exhibition visitors' responses (De Rojas & Camarero, 2008). Through case studies, researchers have investigated the interaction paradigms adopted in museum exhibitions, including hybrid interactive artefacts, i.e., devices that enable visitors to manipulate and interact with physical and digital exhibits (Garzotto et al., 2007). Some museums value interactive exhibits' educational, efficient, and entertaining qualities (Madsen, 2017). To create a positive experience for visitors, museums organise significant events and provide them with various experiential activities. In addition to allowing visitors to view the exhibits, the goal is to provide opportunities for them to gain a deeper understanding of the exhibits (Colbert, 2003). In addition, modern digital applications enable users to experience their emotions, enriching their digital world experience through visual, auditory, and tactile experiences. Ljungar (2017) discusses the digital co-production process, and the audience's reaction to a virtual reality art play is an entirely interactive, gestural, visual, and musical experience. These multisensory experiences can affect the subconscious, allowing visitors to perceive objects more precisely (Bordegoni et al., 2019). However, there are few quantitative studies on the interactions between humans and exhibits (Wang & Xia, 2019). Future research must investigate more complex and multidimensional interaction patterns to improve experiential display and design.

1.1.2 Sensory Experience in Museum and Exhibition Space in Different Fields

Although the progress has been made in the physical and aesthetic aspects of designing interactive exhibition spaces, museum and exhibition planners lack an understanding of how physical design influences the motivation, perception, emotion, and learning potential of unguided museum visitors in informal settings (Annechini et al., 2020). Prior research has demonstrated some real behavioural connections, but it has rarely examined the cognitive processes of art viewers (Jakub, 2014).

Our world is saturated with data sources. As a result, multisensory processing has been a popular area of research. Numerous studies demonstrate that the combination of two sensory interactions can enhance sensory awareness recognition (Sumby & Pollack, 1954), reduce sensory awareness reaction times

(Gingras et al., 2009), and enhance accuracy (Alais & Burr, 2004). In addition, recent research has uncovered a high degree of plasticity in multisensory processes, such as cross-modal simultaneity (Fujisaki et al., 2004). According to the evidence, our visual perception is guided by higher cognitive processes to regions that contain information pertinent to our current objectives (Land & Tatler 2009). Visitor studies and experimental aesthetics (Serrell, 1997; Bitgood, 2010; Tröndle et al., 2014; Kirchberg & Tröndle, 2012; Land & Tatler, 2009) have investigated the cognitive processes of visual attention and memory. ArtLens, an app created by the Cleveland Museum of Art, inspired the multidisciplinary approach utilised in this research (Panourgia et al., 2018). This study aimed to examine the impact of museum atmosphere and memories on the social space of a museum. The "Visual Accessibility" study is predicated on the notion that architecture influences visitors' spatial experiences (Li et al., 2020). The findings support previous research indicating that direct eye contact affects museum visitors' initial tour decisions more than physical proximity. In addition, this result applies to the visitors' preferred mode of investigation. A socio-analytical and psychoanalytical approach addresses the halo that typically characterises the emotional effect of museum displays (Drikker et al., 2020). It is essential to comprehend how museums utilise space and how visitors engage with narratives that connect the present to the past. (Kasperiuniena et al., 2020). A hybrid virtual environment constructed for an architectural museum exhibit emphasises the role of hearing and sound in the visitor's experience. As an alternative, a virtual museum concept that focuses on how visitors perceive art museums is presented (Pottgiesser et al., 2021).

1.1.3 Cognition of Memory

Museums have long recognised the value of multisensory experiences, although they are not always possible. In addition, the method's arbitrariness may generate uncertainty regarding what constitutes interaction and what does not (Morgan, 2012). The sensory experiences and memories of museum visitors have been the subject of extensive discussion, primarily concerning their theoretical aspects (Johnson, Becker, Estrada & Freeman, 2015). However, without actual research, the significance of sensory experiences and their impact on museum visitors' perceptions and recollections remain unclear.

It is a significant discovery that museum memories remain vivid and persistent (Falk & Dierking, 1992; Falk, 2009). Falk and Dierking (2000) and Medved and Oatley (2000) have demonstrated that museum and science centre visitors can be reminded of the natural world in a subsequent "real if similarly stimulated" situation. Psychologists have distinguished between "semantic memory" (associated with conceptual knowledge) and "situational memory" (related to personal experiences of events). It is challenging to objectively compare situational memory because it is a highly personal emotion believed to fade more rapidly with time (McManus, 1993). However, situational memory is more stable and accurate than semantic memory regarding museum visits (Stevenson, 1991; Medved & Oatley, 2000). According to a study conducted by Medved, Cupchik, and Oatley (2004) on the experiences of museum visitors with artefacts, personal relevance and experience play an important role in recall and memory, which are constantly revisited and restructured to impart meaning. Despite the above-mentioned vital insights gained through research, there is currently no defined method for combining museum and psychology-based studies of visitor memory (Fivush et al., 1984).

Memory-related topics are studied in numerous ways, depending on the discipline. Either researchers in the field of museums have examined the relationship between museum visitors' memories and their own identities and motivations, or they have studied both. Archaeologists and psychologists have researched the role of memory in regulating public experience and developed experimental methods for measuring the quantity and quality of encoded and retrieved information. Recent research indicates that few studies have attempted to combine data from these fields to determine the specific effects observed and the effects of sensory experience on humans' ability to form and retain memories (Sweetman, 2020).

This study's limitations stem from three factors: the museum's display space, the product, and the visitor's sensory memory. The purpose of museum exhibitions ranges from disseminating and promoting culture by satisfying the spiritual needs of individuals to assisting scientific research (Wang, 2017). However, with the advancement of technology and people's cultural awareness, researchers assert that museums should focus on satisfying visitors' needs (Madsen, 2017; Vores Museum, 2017). Visitor studies examine the impact and recollection of the tourism experience, whereas museologists concentrate on the numerous functions that museums play in memory formation. It may include multimedia information, artefacts, or a museum visitor's personal/social aspects (Sweetman et al., 2020). Exhibitions are a crucial link between exhibits and visitors (Achiam, May & Marandino, 2014). However, relatively few studies have attempted to determine how different types of exhibits and sensory experiences contribute to forming individual memories (Campbell, 2021). A small amount of research has attempted to determine how different exhibitions and sensory experiences contribute to forming personal memories (Campbell, 2021). In other fields, beginning with Assmann and Czaplicka (1995), the study of the role of memory and material culture has received increased attention over the past few decades, which has led to the development of studies examining how different types of memory are utilised in society. These various techniques have contributed to our understanding of how memories are formed through sensory interaction with material culture. However, there has been little empirical research on why different memories exist for different material cultures.

1.2 Research Gap, Question and Hypothesis

The research gap is focused on exploring whether different sensory experiences within a museum could enhance knowledge transfer or memory retention. This gap is derived from the intersection of three areas of research: the importance of museum space, artefact attributes, and working memory retention (Figure 1-1).

The first factor, the importance of museum space, emphasizes the impact of physical space on visitors' experiences. This includes the design, layout, and presentation of exhibits, as well as environmental and architectural factors. Research has shown that the design and presentation of museum spaces can significantly impact visitors' experiences and perceptions. One way to enhance the perception of space in museums is through the use of environmental and architectural factors, such as lighting, colour, and texture (Bitgood and Kim, 1995). For example, the use of natural lighting can create a more welcoming and comfortable atmosphere, while colours and textures can help to convey a museum's theme or message (Pallasmaa, 2014). Another important factor is the layout of the exhibit space, which can impact visitors' navigation and attention (Mastandrea and Miele, 2018). The use of clear and visible pathways, as well as the placement of exhibits and signage, can help visitors to better understand the exhibit layout and find their way around the space. In addition to physical factors, the presentation and interpretation of exhibits can also impact visitors' perceptions of museum spaces (Falk and Dierking, 1992). The use of interactive and multimedia exhibits, such as virtual reality and touch screens, can enhance visitor engagement and provide a more immersive experience (Chang and Lin, 2018). Furthermore, exhibitions that are designed to tell a story or convey a message can help visitors to connect with the content and create a more memorable experience. The second factor, artefact attributes, focuses on the characteristics of the objects on display, including their material and sensory qualities. This includes the visual, auditory, and tactile features of the exhibit, as well as the historical and cultural contexts in which the artefacts were created and used. The third factor, working memory retention, refers to the cognitive processes involved in encoding and retrieving information from memory and also refers to the ability to retain information in STM and transfer it to long-term memory. This includes attention, perception, and mental rehearsal, which are all crucial for retaining and recalling information about the exhibits. The intersection of these three areas highlights the interconnectedness of different factors that contribute to the overall museum experience. For example, the design of the museum space and the presentation of artefacts can influence visitors' attention and working memory retention. By understanding how different sensory experiences, such as visual or auditory cues, impact knowledge transfer and memory retention, museums can create more effective exhibits to engage visitors and enhance their learning experience.

In summary, this research gap is derived from the intersection of three areas of research that are crucial to understanding how different sensory experiences can enhance knowledge transfer and memory retention in museums. By exploring the relationships between these areas, this study has the potential to contribute valuable insights into how museums can create more engaging and effective exhibitions.

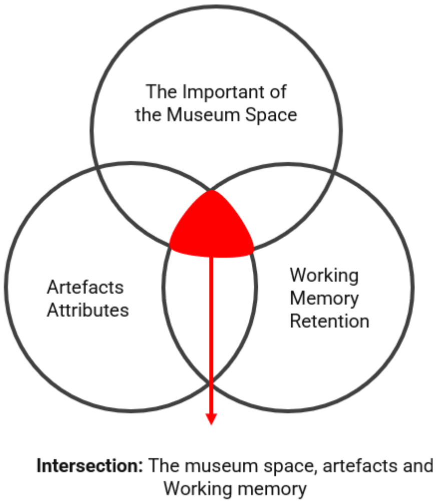


Figure 1-1: Research Gap

Within content to a museum, can different sensory experiences enhance knowledge transfer or memory retention?

We proposed three research questions:

Q1: How can multisensory human experiences be measured or captured?

Q2: Is there a relationship between the visitor's sensory interactive experience and the museum layout design?

Q3: Can this interactive sensory experience and memory experiment method be applied to real-world cases?

Through the research questions, we also formulated the following three hypotheses:

H1: More interactive sensory experiences will enhance the transfer and retention of knowledge in museums.

H2: The experience of sensory interaction has a long-term effect on the growth of visitors' short-term and long-term memories.

H3: As technology evolves, can computer simulations model traditionally learned methods of observing visitor behaviour in museums and exhibits?

1.3 Aim and Objectives

This thesis investigates the relationship between museums, physical space, and human working memory. To achieve our objective, we must examine visitors' sensory behaviour and memory retention to comprehend how they interact with different exhibits and spaces. Furthermore, we will investigate whether memory relationships can facilitate the translation of user knowledge. In addition, we will simulate visitor behaviour using an agent-based model and provide viable solutions for museum layout design and interactive experience design. In addition, the model intends to enhance the experience of human interaction with exhibits, thereby inspiring new curatorial approaches.

The four specific objectives include the following:

Objective 1: Evaluate the museum interaction method, visitors' behaviour and interaction with the exhibits, and the surrounding environment.

Objective 2: Design a sensory memory test with working memory as its core and use online memory tests to challenging working memory retention.

Objective 3: Develop agent-based experience and simulation to evaluate and provide layout design solutions to improve the interactivity between visitors and exhibits

Objective 4: Evaluate the applicability of the agent-based model to the real world by applying it to a case study of MK Gallery, United Kingdom.

The relationship between Objectives and hypotheses for our research objectives, which basically revolve around visitors' memory retention, is shown in Figure 1-2.

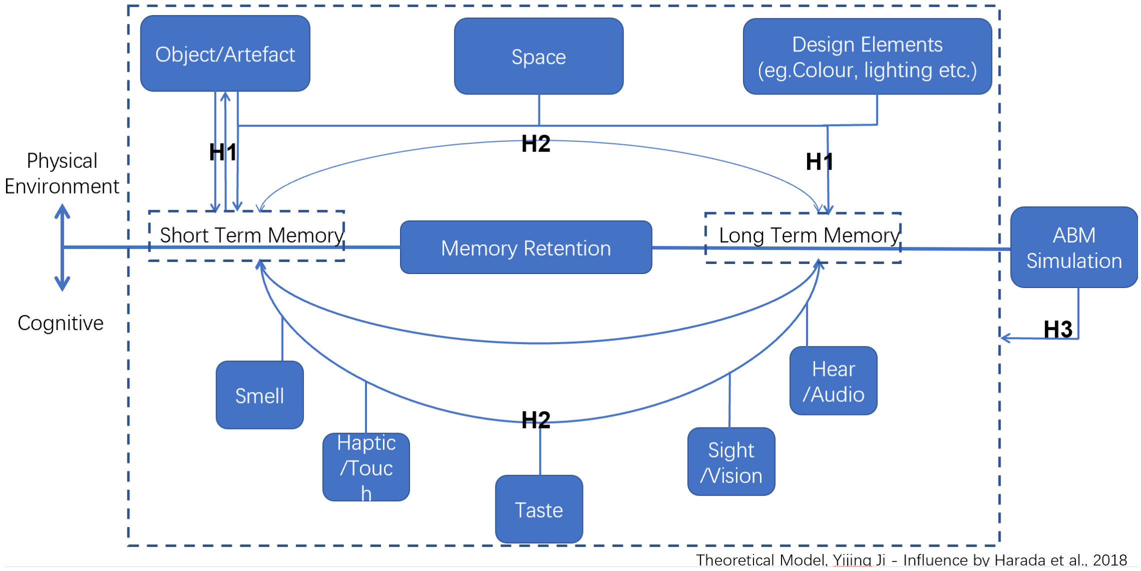


Figure 1-2: Theoretical model: multisensory experience and memory retention

The relationship between research questions, thesis hypotheses, thesis objectives, methods, and outputs are depicted in Figure 1-3:

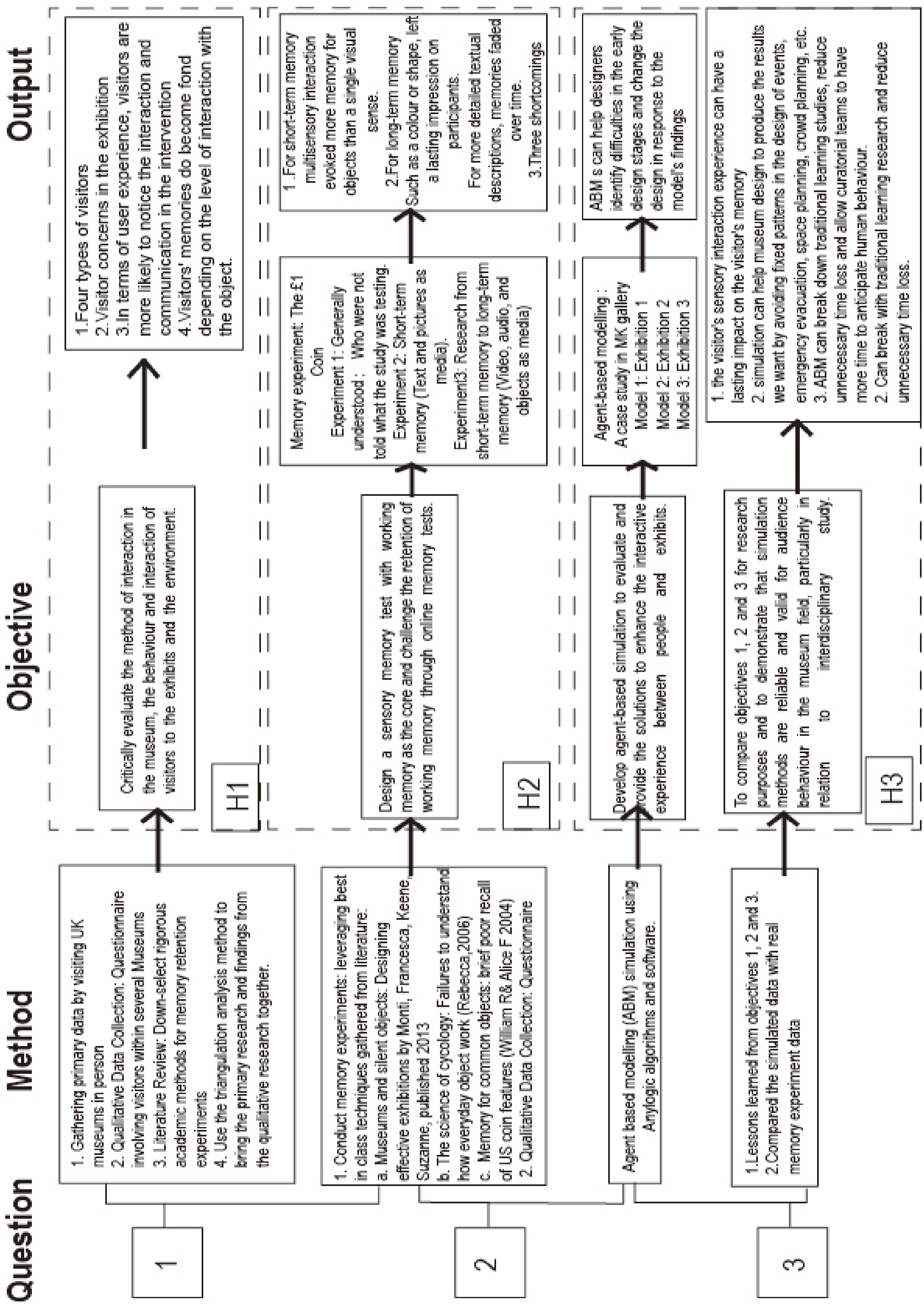


Figure 1-3: The relationship of question, method objectives, hypothesis and output diagram

1.4 Methodology and Design

Our study consisted of four stages: observation and learning; an online experiment measuring multisensory memory; a computer simulation to measure visitors' memory values; and a comparison of the differences between the simulated and actual experimental values.

In the first phase, we systematically gathered data and, following a systematic literature review, located and quantitatively analysed museums in the United Kingdom by museum type. Then, specific London museums were identified, and their visitor behaviour and environmental conditions were observed. Lastly, questionnaires and interviews with participants at the design exhibition were used for qualitative analysis to determine whether the behaviour of today's visitors corresponds to that described in the literature review. Concurrently, a research gap was identified in this field.

Initial impressions from the first stage led us to identify three research gaps in the second stage. Our focus ranges from a wide array of visitor perceptual behaviours to the working memory recall of visitors' multisensory interactions during the visit's middle and end stages. Based on a literature review, 50 classical working memory test techniques were listed in Appendix D. Five methods were chosen as the most likely to be tested. Because of the Covid-19 environment, the methods are reselected, and redesigned so that can be implemented in an online questionnaire-based experiment and observation of sensory interactive memory recall for all students and staff at Milton Keynes Language School.

In stage three, the Covid-19 period reflected the benefits of ABM simulation. The gallery's sporadic closures added great uncertainty to our research, so we shifted our focus from actual visitor behaviour observations to computer simulation. We conducted field studies, partial visitor analyses, and computer simulations of three different thematic types of exhibitions at MK Gallery between the middle of 2021 and the beginning of 2022. The memory recall data for all computer simulations was derived from the output of stage two.

In the fourth stage, we compared actual and simulated data for the third exhibition at MK Gallery, "Laura Knight: A Panoramic View", to determine that computer simulation can also be used to analyse the behaviour of museum visitors in the exhibition space. The final fieldwork employed the learning method "Map cognition experiment and space layout design".

1.5 Structure of the Thesis

<u>Chapter 1. Introduction</u>

This chapter presents the research gap and hypotheses by introducing the real-world context, followed by the development of aims and objectives and a thorough review of the pertinent literature. It then describes the research methodology and design used to achieve the second section's objectives. Finally, it concludes with an introduction to the research strategy, the thesis structure, and a summary of the innovation points.

<u>Chapter 2. Literature Review</u>

The literature review concentrates on four aspects of the overall study. The initial section describes humans' different sensory and behavioural characteristics in museum exhibition spaces. The second section discusses applications and research when single senses are combined into multisensory behaviour. Then, the third section overviews the holistic theories and concepts used in cognitive memory. The fourth section examines the current applications and involvement of Anylogic agent-based modelling in art galleries and museums. Finally, we examine the visitors' memory recall during the exhibition in the current study.

<u>Chapter 3. A Study of Multi-Sensory Experience in United Kingdom Museums</u>

Chapter 3 focuses on the literature review, the field study, and the questionnaire to argue for contemporary museum visitor behaviours, concerns, and memory connections. A series of questionnaires were developed based on observations of communication methods and visitor interaction in twelve London museums and exhibitions. Utilising a final panel survey, the London New Designer Exhibition validated the exhibition-visiting experiences of participants during and after the visitor process.

Chapter 4. Down Selection of Methodology in Techniques

This chapter focuses on introducing and reviewing traditional memory learning theories and techniques. Next, we examine current research on multisensory working memory and offer insight into options for working memory-based approaches. Research on multisensory working memory has shown that cross-modal information interacts with working memory in ways beyond what is typically predicted for conventional storage. Our collection of fifty memory-learning techniques has been screened. The final five most suitable screening methods have been evaluated for suitability.

Chapter 5. A Cyclical Multisensory Memory Experiment: The £1 Coin

Chapter 5 highlights a single-sensory and multisensory memory experiment conducted at MK Language School. The experiments were conducted by selecting and redesigning 50 memory experiments and then comparing participants' long-term and short-term memories at different times under the same sensory stimulation condition.

Chapter 6. ABM and Simulation for Evaluating Impact of Museum Layout on Visitor Memory Retention

This chapter focuses on a computer simulation based on three exhibitions held in the MK Gallery, United Kingdom. It compares the responses of different groups of visitors to the different attributes of the artworks. In addition to applying the new method, the accuracy of the simulated data is determined by correlating it with new data from the traditional memory experiment "Map cognition experiment and space layout design".

Chapter 7. Discussion

This section focuses primarily on discussing and analysing the previous study's findings. It also discusses a better strategy for enhancing the visitor experience to inspire contemporary designers and curators to adopt new curatorial approaches.

Based on the study's findings, the scientific issues raised in Chapter 1 are discussed in the chapter, with the findings of the thesis highlighted. In contrast, towards the end of this chapter, the limitations of the thesis and some refining solutions are presented.

Chapter 8. Conclusions and Future Work

This chapter provides a summary of the previous chapters' findings. The solutions to the scientific inquiries and contributions to knowledge posed by the thesis are provided. This section also addresses future research efforts and directions.

Thesis structure as shown below in Figure 1-4:

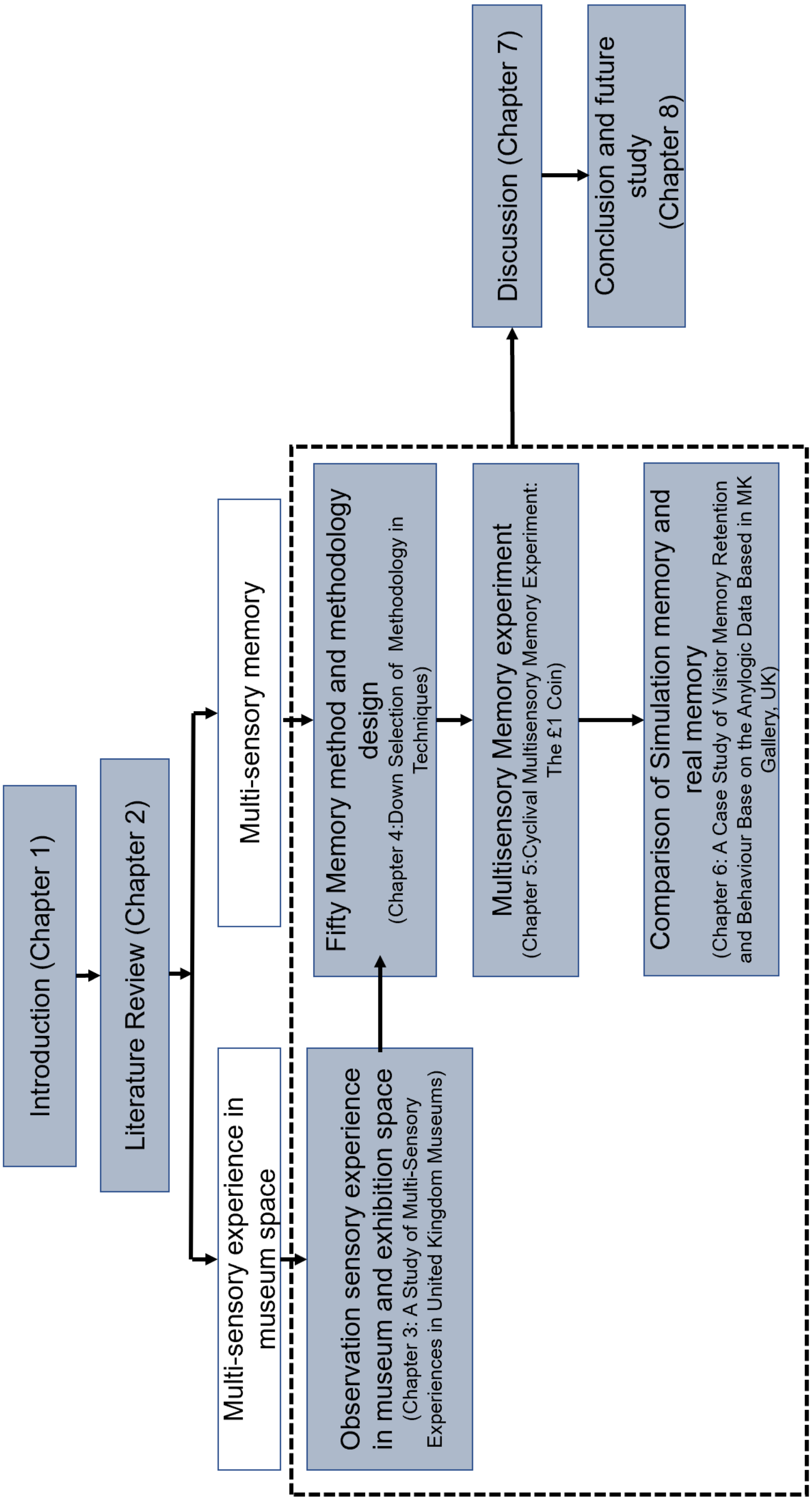


Figure 1-4: Organization of thesis

1.6 Innovation Points of the Thesis

The primary contributions of this research can be summed up as follows:

1. Develop the theory behind additional design elements, such as the sensory behaviour of museum visitors and the spatial design.
2. Open the mind to investigate the effect of multisensory interaction on museum spatial memory by integrating multidisciplinary theories.
3. Develop an ABM for analysing museum visitor behaviour and the effect of layout design on human memory retention.
4. A data-driven simulation approach can provide designers, curators, and gallery managers with a more time- and cost-efficient method for predicting visitor behaviour.

2. LITERATURE REVIEW

2.1 Sensory Behaviour in the Exhibition

2.1.1 The Visual and Auditory Senses

In the fields of psychology and neurology, the concept of cross-modal audiovisual perception has been established, and many studies have revealed a strong link between human perception of auditory and visual stimuli (Chen et al., 2017). There's a lot of crossovers between the functions of the visual system and the auditory system. Both systems differ from somatosensory systems in which they are associated with stimuli at least some distance away from the body. In audio-visual interaction, auditory perception is more temporal than visual perception, while visual perception is more spatial than auditory perception (Shimojo & Shams, 2001). It was also worth noting that vision and hearing are both capable of conveying precise spatial and temporal information. As a result, information about the same (or at least related) objects and events may be conveyed by both vision and hearing. The interplay between the visual and auditory systems may be useful in a variety of ways because of this functional overlap. To begin, the 'missing component' may be found inside each of the five senses. For example, it is not always possible to locate objects that are visually obstructed or placed out of view, or when in total darkness. Such voids may be filled by the auditory system. Visual and auditory spatial information complement each other in a way that provides obvious advantages for people and other animals, whether they are navigating congested cities, hunting or avoiding predators (David and Jennifer, 2006). For decades, research has been predominantly visual and auditory, which is also included in the field of human–computer interaction (HCI), although nature has given us additional senses to perceive and interact with the world around us. Researchers and designers in the field of HCI are increasingly interested in designing activities and experiences that include the senses of touch, taste and smell (Obrist et al., 2017).

2.1.2 The Haptic Sense

In museums during the 17^{th} and 18^{th} centuries, social elites were allowed to wander among the artefacts, picking them up, holding them and feeling them (Johnson, 2002; Classen, 2005; Chatterjee, 2008; Candlin, 2010; Howes, 2014). However, as museums became more accessible to the general public in the late 18th and early 19th centuries, museums found it necessary to restrict such physical contact with the artefacts out of a concern for their preservation and maintenance (Pye, 2008; Clintberg, 2014). According to some studies of haptic interaction, the hand can be used as an 'optical prosthesis' to enhance visual contact with objects, and that when we actively explore an object with our hands, information about the object is more readily available compared to that generated by exclusively visual exploration (Hetherington, 2002). We have a limited grasp of how tactile systems recognise objects compared to how visual systems recognise objects. Candlin (2006 & 2009) claims that touching artwork offers an instant knowledge of the context in which it is situated on the surface. For example, individuals may visibly pat the head of a lion sculpture or touch the breast of a figure sculpture, or they may communicate their emotional response through points, strokes and caring touches. Many researchers have worked to uncover the unique properties of tactile stimuli and the specificities of tactile experience design in order to create emotionally engaging and meaningful experiences (Schneider et al., 2017; Gatti et al., 2013; Seifi & MacLean, 2017). Nevertheless, the general consensus is that our knowledge of how haptic systems facilitate object identification is inferior to our knowledge of how optical recognition does so (Klatzky, 2011).

Curatorial methods, as well as exhibition design and behavioural regulations in art museums, emphasise visuals over other senses, implicitly conceding the objectivity of the visual over the subjectivity of other senses (Bal 2003; Bennett, 2006). However, tactile experiences (such as touchscreens and multi-touch tables) in museum settings are becoming more readily available, making art more accessible and interesting (Correia et al., 2010; Dijk et al., 2012; Hornecker, 2008; Ma et al., 2015). In addition, Bezemer and Kress (2014) describe three different ways of "touch communication": the first as a way of communicating with people, the second as a way of transmitting ideas, and as part of a broader mix of interactions. Besides, the meaning potential of certain artworks and exhibition settings (Bakhtin, 1986), as well as the communication role of touch in human connection, have been conceptualised as being embodied in physical and social situations. Researchers have contrasted the amount of time spent viewing art in genuine museum settings versus laboratory settings (Smith & Smith, 2001; Carbon, 2017). Additionally, some museums offer tactile sessions for visually impaired persons as well as multimedia interactions utilising multi-touch PCs, which enable visitors to view information about the artwork and label it with a presentation (Correia et al., 2010). Although the participation and inclusion of diverse audiences has expanded while multisensory perspectives have become increasingly developed in aesthetics, art, and neuroscience (Carroll, Moore & Seeley, 2012; Bacci & Pavani, 2014), few empirical studies have investigated the multisensory dynamics of visitors' natural interactions with artworks that allowed for touch.

2.1.3 The Olfactory Sense

Humans have a variety of senses that interact with the environment around them. In the sensory system, vision and hearing are traditionally the primary senses, and then touching, tasting, and smelling are sometimes labelled as secondary or "lower" senses (Spence, 2011). Research into HCI is increasingly enthralled with the ways in which touch, smell or taste may contribute to the field. In-vehicle olfactory interaction by Dmitrenko et al. (2016), the Digital Flavour Interface by Ranasinghe et al. (2014), and the additional value of tactile input to audio-visual material by Maggioni et al. (2016) are recent examples of such research. Scent is also occasionally used in art to enhance a visual experience. Tate Britain had an exhibition titled ‘Tate Sensorium’ in 2015, which sought to offer a fresh, multi-sensory appreciation of the exhibits. Flying Object in London used a variety of British paintings as a starting point for a variety of olfactory experiences and other artworks – for example, by combining the smell of grass and dirt with characters from painting by Francis Bacon. Other pieces of art use a similar technique, such as by pairing paintings of boats with the smells of fuel and tobacco, or paintings of contemporary houses with the smells of Pledge-brand furniture cleaner. In this case, the aroma acts as a metaphor for the painting's visual content. Anne Nieuwhof's Inhaling Art at the Netherland's Van Abbe Museum (2014) employed aroma to reinterpret visual art in a museum tour. Visitors were invited to open a jar nearby a work of art to appreciate the aroma connected with it. At the Metropolitan Museum of Art in New York, Ezgi (2015) applied powdered spices, incense and scents directly to the paintings, rather than utilising a scent delivery system. Floral and brine scents provided realism to Monet's Garden at Saint Adelaide. The 'olfactory serenity' that disrupts the pre-existing artistic experience may have been achieved through innovative efforts (Rodolphe, 1996). Fragrance production is akin to creating art, while fragrance selection is akin to curating it.

Various museums have experimented with multi-sensory integration by including scent into their exhibits. The National Museum of Singapore's Laura Miott exhibit used the smell of street food to depict post-war social history. She created an olfactory delivery system that allows visitors to have an individualised olfactory experience that brings back memories of post-war Singapore's culinary landscape. The fragrances of plants and medicines were employed to symbolise indigenous cultures in another show in 2015. Older tourists were able to relive their social histories via the use of the particular smells, while younger visitors were able to feel the same nostalgia. For an exhibition on Singapore's changing environment, she employed rotting and floral odours to portray urban progress from polluted rivers to green cities (2016). Aromas such as those of baby powder and scotch tobacco and dark chocolate and leather were all represented in Lai's (2015) 'Universal Scent Blackbox', a work in which a box emits five distinct scents. Visitors to the installation may release scents into the air around them, and the other way around. Visitors were fascinated by this olfactory interaction, which functioned as an educational investigation of the olfactory interface.

However, as the work of Köster et al (2014) illustrated, a person's emotional connection to their environment is what fragrance serves in daily life rather than helping them recall names or distinguish between different sources. Scent-delivered artworks also drew more visitors and stayed longer, according to an experiment conducted by Lai in 2015. At comparison to other visual artworks on the same level, visitors would spend more time in this exhibit. This is a process that will take them a long time to complete.

2.1.4 The Sense of Taste

Recently, interest in multisensory flavour perception studies has risen significantly. It is not as straightforward as it seems to pin down what makes something taste good or bad. Our senses of taste, smell, and touch are all activated concurrently when we eat. As a result, everyone agrees that flavour may be experienced in several ways. However, there is still much disagreement about the appropriate number of modalities to include (Spence, 2013). The term 'fruity', 'meaty', 'floral', 'herbal' and other similar adjectives describe the mix of gustatory and olfactory impulses that go into creating a flavour. There were two distinct types of postnasal scent: the nasal odour when we sniff and the postnasal fragrance after we swallow and expel air from our noses (e.g., Rozin, 1982). Since these two senses of smell have been distinguished for over a century, researchers have only lately been able to substantiate the argument that separate brain substrates may truly be involved in processing these two senses of smell (Small et al., 2005). Flavour is created when the postnasal fragrance interacts with the gustatory stimuli. Trigeminal input also adds to the experience of flavour in addition to these two senses. Other senses, like as vision, hearing and oral somatosensory, are ambiguous regarding their role in the sensation of taste (Piqueras-Fiszman and Spence, 2014).

Taste was not just one of the fundamental human senses, but it was also tightly tied to and rewarded by human emotions (Peng, 2015). Researchers have found evidence that taste may impact the way people think about the world and make decisions (Obrist and Job, 2014). According to Obrist et al., (2017), the five fundamental tastes have distinct temporal features, which they explained using dual process theory (Kahneman, 2012), this demonstrated two different ways of thinking. Fast and automatic associative thinking with a strong emotional connection may be found in System 1, which relied heavily on the power of intuition. Reassuring judgements and attitudes had a greater impact on the reasoning-based system 2, which were slower, more unpredictable, and subject to judgements made intentionally. Previous studies have shown that individuals become more reasonable and hesitant to act in their decision-making when they are baffled by the explosive but transitory feeling of sour taste. In contrast, residual sweetness was supposed to drive more intuitive decision-making and speedier action because of its frequently felt pleasantness (affordability of ingestion). In a prior research, bitterness was shown to have the same effect as sweetness in speeding up decision-making by clearly indicating unpleasant flavours (tolerance for rejection). Savoury and fresh flavours, on the other hand, remained a mystery.

Cognitive psychology and cognitive neuroscience, for example, aimed to get a better scientific understanding of how humans perceive flavours in food. Gastronomic, olfactory, visual, tactile, and auditory cues may have altered the taste or flavour of a food or beverage in an experiment (Okamoto et al., 2009; Gallace et al., 2011; Spence, 2011; 2014; 2017). While food taste and flavour were important aspects of hunger and perception, multisensory experiences surrounding these aspects had an important psychological and physiological function when they occurred beyond one's comfort zone (such as at a restaurant) (Kivela and Klotz, 2006; Kim et al., 2019). Tests of this sort were especially infrequent when applied to food museum surroundings, despite their rising appeal as tourist attractions throughout the globe (Spence, 2017)， south Korea's Kimchi Museum is the notable example.

2.2 Research and Application of Multisensory Behaviour

Multisensory integration at museums was most often achieved by combining the senses of touch, visual, and sound. Studies on particular senses including vision (e.g. Mateucci, 2013), hearing (e.g. Pilcher, Newman and Manning, 2009), smell and taste (e.g. Dann and Jacobsen, 2003) have been conducted (Bruwer, Coode, and Herbst, 2013), this was based on the work of Saliba and Herbst. However, research showed that visitors' total experience was not dominated by any one sensation (Cohen and Cohen, 2019). Distinct sensory messages may be combined to generate themes and express destination offerings, as well as encourage unique experiences desired by groups of tourists with different traits (Agapito, Valle and Mendes, 2012). It could be possible to 'touch things' at the Victoria and Albert Museum in London (VAM, 2017), for example, by looking at cunning owls and diverse wood sculptures in the Sculpture Gallery. Visitors could also touch a button adjacent to an item to hear an audio explanation linked with it. Similarly, a sandbox for archaeological workshops was presented by Ciolfi and Bannon (2002), which allowed the youngsters present to 'play archaeologist'. These prototypes were built by Harley et al. (2016) to transmit and contextualise the history, sensations, and messages of prayer nuts. Sensory interactions including scent, touch, and sound as well as visual and audio input related to the artefacts are provided by these 3D printed tangible prototypes. Museums and galleries have led the way in integrating and stimulating many human senses to explore new modes of creative expression and raise awareness of artefacts on show among a larger audience. A substantial influence on the visitor's experience, especially in establishing powerful sensations, may be achieved by the integration of touch samples, sounds and fragrances with interactive components (e.g., role-playing sensory devices) and dynamic displays to accompany items. Complete focus and absorption in a single activity is referred to as 'mind flow' (Csikszentmihalyi, 1997). The Jorvik Viking Centre (Jorvik, 2017) was another innovative museum that uses multimodal stimuli to enhance the experience of a tour of York's Viking heritage. Historic artefacts (Viking-era artefacts), unsalted dried fish from the Viking diet and comparable things on show may be touched by visitors. They could also smell the scent of the associated objects on display. When it comes to the sense of touch, Loscos et al. (2004) demonstrated how visitors may experience virtual 3D artwork (such as sculptures) by placing a haptic device on their right index finger and receiving tactile input. The usage of this technology enabled the user to feel the artwork's curves and hardness up and personal via their fingertips.

It was possible to enhance a visitor's memory recall by engaging their five senses throughout their stay (Meacci and Liberatore, 2018). In other words, the more sensory systems utilized by the event, the more effective and memorable the effect of sensory interaction becomes (Pine and Gilmore, 1998). The five senses (individually and collectively) of each tourist influence their perception and interpretation of the location (Hulten, Broweus and van Dijk, 2009). It has been found that the five senses work together to create a multisensory picture of each location, according to Xiong et al. (2015). Visual perceptions include green mountains and water; auditory impressions include traditional tunes, taste impressions of local wines, smell impressions of local food, and touch impressions of the wind on your skin at night.

2.3 Memory

2.3.1 The Concept of Human Memory

Today, memory is defined in psychology as the ability to encode, store and retrieve information (Squire, 2009). We can recall subjective personal experiences at will. This way of thinking about memory has led many to wonder if we can have the maximum number of memories. However, memory was not a concrete, inherent state in the brain, but a dynamic chemical reaction between neurons (Gregorio and Aaron, 2019). Not all academic scholars agreed that memory is a neurocognitive faculty that should be examined in a controlled setting in order to gain the purest perspective of its functioning in the person (Bruner, 1994; Fivush, 2011). Sensory, short-term, and long-term memory were all significant aspects of memory, according to psychologists. Each of these kinds of memory have their own unique characteristics, for example, sensory memory is not consciously controlled, short-term memory can on hold limited information, and long-term memory can store an indefinite amount of information (Bramham and Messaoudi, 2005).

Similar to modern research, memory in medieval cultures was thought to have originated in sensory perception, involving physiological processes in the brain, and having the function of storing, categorising, and retrieving material. Memory is an internal mental experience of the individual that transcends social context and culture (Gregorio and Aaron, 2019). Bartlett (1995) based his study of memory on meaningful material (e.g., stories) on the hypothesis that memory occurs in an organised environment or schema in which it is reconstructed from an individual's general knowledge of what is relevant. ‘Orthodox psychology of memory' was directly criticised by Ulric and Neisser (1982). He argued that a naturalistic analysis of 'the practical uses of memory in humanly understood circumstances' was necessary to understand its purpose and function (Neisser 1982). The emerging science of memory is concerned with the question of how memories are consolidated and processed. In most organisms, long-term storage of memory occurs at the synaptic level (Bramham and Messaoudi, 2005), but in complex organisms like ours there is a second form of memory consolidation: the systematic integration of movement, processes and more permanent stored memories (Frankland and Bontempi, 2005).

There are a number of models that illustrate how memories are consolidated in cognition. It is assumed in the single-system paradigm that the hippocampus promotes neocortical encoding and storage of long-term memories via improved connection, resulting in memory independence from the hippocampus eventually. Multiple trace theory proposes that each memory has a unique code or memory trace that continues to involve the hippocampus to some extent (Hintzman, 1990; Versace et al. 2014; Briglia et al. 2018). In another way, according to Wiener (1988), memory is thought of as a type of rich energy, which is subsequently processed in a manner that minimises the brain's energy consumption (Friston, 2010; Van der Helm, 2016).

There have been several theoretical debates and empirical investigations on sociocultural impacts on memory during the last two to three decades, including contributions from academics in a variety of fields of psychology and other sciences. For instance, research on memory paradigms by Duffy and Kitayama (2007) and Schwartz et al. (2014) indicates cultural disparities in memory failures for automated procedures, indicating that people's cognitive styles are internalised. According to the memory context effect, people's assessments of stimulus elements (such size) are impacted by previously given stimuli (i.e., information accumulated in memory). In general, more and more researches from different fields begin to pay attention to memory research, which also reflects the comprehensiveness and interdisciplinary nature of memory research under the multicultural background.

2.3.2 Influential Memory Theories and Studies in Psychology

Memory has been the subject of research by many psychologists in the 20th century and remains an active area of research for cognitive scientists today. Below we have selected some of the most influential studies, experiments, and theories (Figure 2-1) that will continue to guide our understanding of how human memory functions.

1. Multi-Store Model (Atkinson & Shiffrin,1968)
2. Levels of Processing (Craik & Lockhart, 1972)
3. Working Memory Model (Baddeley & Hitch, 1974)
4. Miller's Magic Number (Miller, 1956)
5. Memory Decay (Peterson and Peterson, 1959)
6. Flashbulb Memories (Brown & Kulik, 1977)
7. Memory and Smell (Cann & Ross, 1989)
8. Interference (Underwood & Postman, 1960)
9. False Memories (Loftus & Palmer, 1974)
10. The Weapon Effect Eyewitness Testimonies (Johnson & Scott, 1976)

Figure 2-1: Influential memory theories and studies in psychology

1. *Multi-Store Model* (Atkinson & Shiffrin,1968)

The multi-storage model of memory was first presented by Richard Atkinson and Richard Shiffrin in 1968. Sensory, short-term, and long-term storage are all options in this strategy for storing information. The more we practice something in our brains, the more it passes from one level to the next, but if we don't pay attention to it, it will disappear (Figure 2-2).

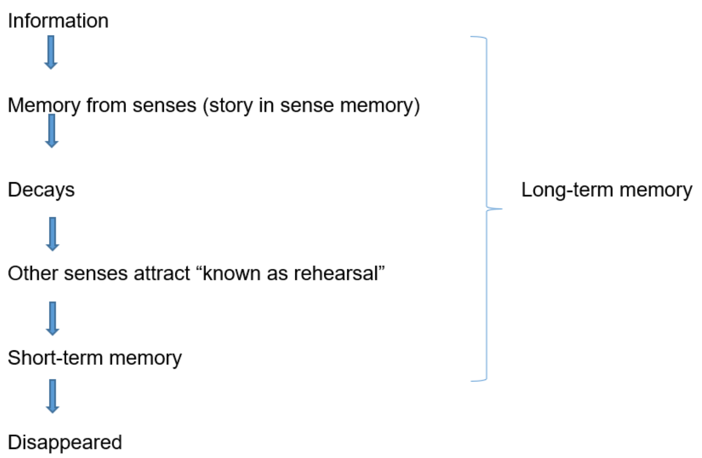


Figure 2-2: The process of memory state stages

Our short-term memory, which has a limited capacity, permits us to retrieve knowledge that is critical to our present circumstances. As a result, to retain knowledge for a longer period, we must repeatedly practice recalling it from our short-term memory. Recalling an experience from the past or learning an information by heart might also fall under this category. Atkinson and Schifrin (1968) think that this knowledge may be stored in the long-term memory bank for years, decades, or even a lifetime by rehearsing. People we encounter, significant events in our lives, and other essential data are stored in our long-term memory from sensory and short-term memory.

2. *Levels of Processing* (Craik & Lockhart, 1972)

To counter the multi-store model's claims about memory, Fergus Craik and Robert Lockhart presented a new theory in 1972 dubbed the level of processing effect. The strength of a memory trace relies on the quality of processing or repetition of the input, according to this hypothesis. In other words, when we think or do something repeatedly, it will stay in our memory for a long time, sometimes even becoming muscle memory (Craik and Lockhart, 1972).

3. *Working Memory Model* (Baddeley & Hitch, 1974)

Baddeley and Hitch (1974) said that short-term memory (STM) storage was too simple, so they came up with a new model called working memory. This model replaced STM with working memory.

The working memory model offered two components that each concentrate on a distinct sort of sensory information: a visuo-spatial sketchpad (the ‘inner eye’) and an articulatory-phonological loop (the ‘inner ear’). Both operate independently of one another but are controlled by a central executive that gathers and manipulates data from the other parts in a manner similar to how a computer processor manipulates data stored separately on a hard drive.

- The visuo-spatial sketchpad

According to Baddeley and Hitch (1974), manages visual data—our observations of our surroundings—and spatial information—our comprehension of the size and placement of things in our environment as well as their position in reference to ourselves. By doing so, we may interact with objects—picking up a cup or avoiding running into a door, for instance:

A person may remember and think about visual information that has been stored in the long-term memory with the use of a visuo-spatial sketchpad. Your capacity to picture someone's face while trying to remember them requires your visuo-spatial sketchpad.

- The articulatory-phonological loop

The voices and sounds we hear are handled by the articulatory-phonological loop. Auditory memory traces are often gone, but they may be practised using our ‘inner voice’, which can help us remember a certain sound better.

4. *Miller’s Magic Number* (Miller, 1956)

Before the working memory model, the American cognitive psychologist George A. Miller questioned the limits of STM capacity (Figure 2-3). Miller's understanding of the limits of human memory applies both to short-term storage in the multi-storage model and to Baddeley and Hitch's working memory. Only through continuous effort to rehearse information can we remember data longer than a short period of time.

The Magic number 7 is Miller’s idea. He thinks that most adults can store between 5 and 9 items in their short-term memory (STM). STM can hold 7 (plus or minus 2) because it only has a certain number of "slots" to store items.

However, Miller did not specify how much information could fit into each slot. In fact, if we can "block" information together, we can hold more information in our short-term memory.

Miller's theory was supported by various studies, such as Jacobs (1887). He gave the number span test to every letter and number in the alphabet, except for “w” and “7” because they have two syllables. He found that people are more likely to remember numbers than letters. The average span of letters and numbers was 7.3 and 9.3, respectively.

The limits of human memory apples to both

1. Short-Term Store in the Multi-Store Model
2. Baddeley& Hitch Working Memory

Figure 2-3: Miller's understanding of the limits of human memory applies

5. *Memory Decay* (Peterson & Peterson, 1959)

Measure memories 'longevity'.

Following Miller's 'magic number' on the capacity of STM, Peterson and Peterson (1950) set out to measure the longevity of memory - to study how long it lasts without rehearsal before it is completely forgotten.

6. *Flashbulb Memories* (Brown & Kulik, 1977)

Many people seem to have a vivid memory of particular moments in history (Brown and Kulik, 1977). When psychologists Roger Brown and James Kulik wrote a paper about flashbulb memory back in 1977, they talked about vivid and detailed snapshots that are often, but not always, made during times of shock or trauma. When we hear about these kinds of things, we can remember small details about our own lives while doing other things that aren't very interesting. There is another reason why an event can affect us: It can make us remember flashbulb memories that we don't even know about.

7. *Memory and Smell* (Cann & Ross 1989)

Scientists at the University of North Carolina did a study in 1989 to see if smell could help people remember things better when they were storing and retrieving them. People were better at remembering things when the odour at the time of encoding and the odour at the time of recall were the same (Cann and Ross, 1989). In this way, these findings show that even though our sense of smell and memory are linked, our more primitive ancestors, the animals, didn't use this link as much to stay alive as we do now.

8.Interference (Underwood & Postman, 1960)

Interference theory says that we forget things because other memories get in the way of us remembering them. Retrospective interference: new information interferes with our memories of the past, while information we already know can make it hard to remember new information (active interference).

During a 1960 experiment, two groups of people were given a list of word pairs to remember so that when they were given the first as a stimulus, they could remember the word pairs. When the two memories are semantically related, both types of interference are more likely to happen. There were two groups. The first group was given a list of words to learn, and the second group had to remember a second list of word pairs. During the test, both groups were asked to think of the words in the first list. Those who had just learned that list could think of more words than the group that had just learned the second list (Underwood and Postman, 1960). This supports the idea of retroactive interference: words from the first list are more likely to come to mind when the second list is shown.

Interference also operates in reverse: existing memories may sometimes impair our capacity to recall fresh information. This may occur when you obtain a job schedule, for example. When you are given a new schedule a few months later, you may find yourself clinging to the previous time. The timetable you are already familiar with may cause confusion with your recall of the new schedule.

9. *False Memories* (Loftus & Palmer, 1974)

Cognitive psychologist Elizabeth Loftus has spent much of her life studying the reliability of our memories, particularly in situations where their accuracy has wider implications. Loftus discovered that the phrasing of questions used to elicit narratives of events may result in witnesses testifying falsely about events, particularly when the accuracy has broader ramifications, such as eyewitness evidence in criminal prosecutions. Loftus presented a video of a car crash to a group of volunteers in one experiment. The vehicle was travelling at a variety of speeds. She then inquired about the car's speed, using a different word to elevate the severity of the crash. Loftus discovered that when participants were asked if the collision was violent, they disregarded their video views and assured that the automobile was travelling faster than the collision was (Loftus and Palmer, 1974).

As Loftus shown, the use of framing questions may obstruct existing event memory in the retrospective.

10. The Weapon Effect on Eyewitness Testimonies (Johnson & Scott, 1976)

The capacity of a person to recall experiences is inextricably linked to not just rehearsal but also to the amount of attention given to the event at the moment it happens. The influence of weaponry on eyewitness testimony was investigated in a 1976 experiment in which participants sat in a waiting room and observed a person exit the room with a pen in one hand. Another set of volunteers overheard a dispute and subsequently saw a guy exit the room carrying a bloodstained knife. Later, when participants were asked to identify the person in the line, those who saw them holding a weapon performed worse than those who saw them with a pen (Johnson and Scott, 1976). The weapon diverted witnesses' attention, impairing their ability to recall other facts of the occurrence.

2.4 Visiting in the Museum or Exhibition

Social history museums are particularly interested in the influence of artefacts and displays on the visiting public. The museum field, in particular, emphasises insights about the emotional responses of visitors to artefacts seen during museum visits that cause them to recollect their own history (Arnold-de Simine, 2013; Crane, 2000). Medved, Cupchik and Oatley (2004) examine visitors' interactions with artworks, finding that personal significance and experience play a core part in memory, and that memories are frequently revisited and reorganised in an attempt to provide meaning for the original encounter. Indeed, social history museums that portray current culture provide a snapshot of society in a specific location and time period, with the ability to elicit deep emotional connections and nostalgic recollections about the visitor's past and personal identity. This evocation not only conjures up nostalgic emotions for the visitor, but also elicits a powerful emotional reaction during a modern museum visit. This is especially true for senior guests who have lived through the era depicted in the show (Levin, 2007; Anderson et al., 2016, 2017).

To create rich and gratifying experiences, museums must attract visitors with a diverse range of prior knowledge and interests, who like engaging with the museum in ways that are meaningful to them, and who possess a variety of sensory, cognitive, and physical skills. While industry participants' interest in research and practice in multimodal museums has risen in recent years (Levent & Pascual-Leone 2014), the majority of museums continue to engage visitors primarily via a visual environment. However, in exhibition venues, only visual exploration (perceptual presentation) might result in ‘shallow’ processing, which processes information based on its surface characteristics. It is more in-depth processing and stimulation that has the ability to enhance the visitor's memory (Ekuni, Vaz & Bueno 2011). Additionally, when interpretation is offered, stimuli may be processed at many levels, ranging from ‘shallow’ processing based on perceptual experience (colour, form, brightness, loudness, etc.) to ‘deep’ processing, in which stimuli provoke personal analysis of meaning, inference, and effect (Ekuni, Vaz & Bueno 2011). Additionally, the variety of visual stimuli given in museum settings might be overwhelming to visitors (Bitgood et al., 2013). This often results in what is referred to as browsing behaviour, in which individuals spend just a little amount of time in front of a single exhibition or artwork (Smith & Smith 2001). Smith and Smith's (2001) research of art museums discovered that, even when visitors paused to admire an artwork, the average viewing duration was only approximately 17 seconds. This indicates that for many people, a visit comprises of several rapid glimpses at artworks rather than extended contemplation of a few select pieces. Even when visitors stopped to observe the show, there were disparities in how their knowledge of the art and artefacts was probed. People are becoming more interested in slow-viewing workshops, in which memories grow more spectacular, and academics have urged visitors to examine two or three pieces attentively to demonstrate what they may have missed (Brown, 2018; Roberson, 2011; Rosenbloom, 2014; Tishman, 2017). According to studies comparing the viewing habits of art specialists and non-expert visitors, art professionals are more inclined to scan for composition and form, whilst non-art experts are more likely to be attracted to identifiable aspects (Koide et al. 2015).

In the field of museum studies, the importance of incorporating sensory experiences into exhibition design is widely acknowledged. However, there is a lack of actual research on the impact of sensory experiences on museum visitors' perceptions and recollections. Despite the growing interest in multisensory engagement in museums, two studies have examined how sensory stimuli affects visitors' learning, memory, and emotional responses.

Falk and Dierking (1992) explored the role of sensory experiences in visitors' learning and memory of natural history exhibits. The study found that visitors who engaged with exhibits using multiple senses (e.g., touch, smell, and sound) had better recall and more positive attitudes towards the exhibits compared to those who only used visual stimuli. Similarly, Boerner and colleagues (2019) examined the effects of olfactory cues on museum visitors' emotional experiences. Their study found that visitors who were exposed to pleasant odors in an art museum reported higher levels of positive emotions compared to those who were not exposed to any scent.

As a result, the field of museum studies still lacks a comprehensive understanding of the effects of multisensory experiences on museum visitors' perceptions and learning outcomes. Further research is needed to explore the potential for integrating multisensory experiences into museum exhibit design.

2.5 Approaches to the Agent-Based Modelling Simulation of Human Behaviour

The power of the museum experience is to unlock underlying memories and maintain or restore visitors' sense of self-identity. Social history museums, which depict and interpret contemporary history through objects, videos, dioramas and displays, can make deep connections with visitors' pasts - especially when displays come from their own lives and life experiences (Anderson, Shimizu & Iwasaki, 2018). This finding hints at the importance of visiting museums for the social sharing function of self-memory. If a person engages in cultural activities in the form of leisure activities, hobbies and interests, it seems likely that memories of these activities will become part of the current self-awareness and social dialogue, thus facilitating the accessibility of these memories through coherence and rehearsal. Early positive experiences in museums may also influence the frequency of subsequent visits (Hutchinson et al.,2020).

Moreover, it has been shown through visitors' memories that participants with interaction recall more than those without interaction. Multi-sensory interactive design in museums or exhibitions goes beyond superficially enjoyable design. It plays a fundamental role as a catalyst and mediator of emotional engagement, recall, personal connection, and reflection, which can help visitors to understand and appreciate art, history, and culture. The multi-sensory interactive setting emphasises the relationship between people and the world, allowing visitors to retrace the museum's objects, phenomena and culture through their memories. Furthermore, through the engagement of multiple senses (including sight, sound, smell, taste and proprioception), sensory connections prove to be enlightening, meaningful and engaging. It plays an essential role in creating emotionally, reminiscently and educationally stimulating immersive experiences (Wang, 2020). Visitors believe that increased forms of interaction can enhance the permanence of their memories (e.g., thoughts, emotions), help enrich visitors' memories of cultural events and develop the potential for lasting memories (Hutchinson et al.,2020).

The analysis of museum visitor behaviour has a long tradition (Robinson, 1982) and is growing in importance as visitor flows to increase and digital technologies become more accessible (Falk, 2016; Yalowitz & Bronnenkant, 2009). In their quest for better development and experiences, many museums have developed into new incubators, using technology to enhance their collections' interpretation, presentation, and curation. The rapid growth of digital media has had a massive impact on the work of curators and other museum professionals. They often collaborate with professionals from different areas of the creative industries to create new places, new audiences and renovated visitor experiences within and beyond limited physical spaces (Chivăran et al., 2021). Integrating sciences such as psychology, computer science, statistics, the physics of complex systems, modelling and optimisation theory requires increasing interdisciplinary expertise (Lv, Qiao & Singh, 2020).

Agent-based modelling (ABM) is an innovative computational approach used to model complex systems and the behaviours of individuals within these systems. In recent years, ABM has been applied to measure visitor behaviour within museum design. ABM has the potential to help museum designers and planners to better understand visitor behaviour and to optimise exhibition design. Pfoser and colleagues (2016) applied ABM in museum design to simulate the movement of visitors within the museum in response to different design features. The results of the study showed that there were significant variations in visitor behaviour based on the location and design of exhibits, the density of visitor traffic, and the layout of the space.

Yim and colleagues (2018) used ABM to investigate visitor behaviour in a natural history museum. They conducted surveys and observations to gather data on visitor behaviour, and then used ABM to model visitor movement and interaction with museum exhibits. The results showed that visitors tended to cluster around certain exhibits, and that this behaviour was influenced by factors such as the time of day, exhibit popularity, and exhibit placement.

These studies demonstrate that ABM can provide valuable insights into visitor behaviour within museums. By modelling visitor behaviour in response to different design features and layouts, ABM can help museum designers and planners to optimise space utilisation, improve visitor experience and engagement, and ultimately enhance the overall performance of the museum. Nevertheless, early design decisions were incomplete and inherently wrong, which significantly impacted eventual performance (Attia et al., 2012). ABM is one of the methods used to simulate the design, and it helps predict human behaviour, for example, in everyday life (Schaumann et al., 2015) and evacuation (Hong & Lee, 2018). However, as most museum buildings are not designed with ABM, visitors face various problems in different environments. For example, some museum departments are not ideal users because of their poor location or because certain building parts do not respond to high usage. In architectural design, the human element plays an important role, and the use of multi-intelligent body systems to transfer human movement into the simulated environment is inevitable (Çağdaş, 2009). Academic research has explored complex and ambiguous design processes (Horvath, 2004), and in recent decades various generic models have been developed for use in general environments (Ulrich & Eppinger, 2011).

Although their implementation in many engineering and industrial design schools has taken place, there is still a lack of standardised models in architectural design studios (Hassan et al., 2010; Hong & Lee, 2018; van Dooren et al., 2014). However, the methods presented in ABM simulations can provide designers with an effective tool based on simulations being used as a primary technique for design evaluation and validation (Shephard et al., 2004). An example of this is crowd flow or emergency evacuation in the construction sector. Researchers have provided a prototype of an agent-based model that uses the concept of usability to simulate the decision-making process during evacuation to model the behaviour of evacuees on underground platforms during routine and emergencies (Uddin et al., 2021). On the other hand, ABM research can help designers develop new ways of thinking about building users and incorporate their needs into the design process (Hong et al., 2016). For example, in architectural design, zero-energy building design uses computer-generated information to help make decisions about creating energy-efficient structures (Goldstein & Khan, 2017).

Another example is interior design, which can help designers create a more efficient layout. The future could include features such as: using a system with numerous floor plans, analysing different dates and times (user time rates), architect-friendly interfaces (executing changes in real-time), and using spatial integration methods to analyse results. Studies such as these can be carried out in any public implementation area, especially transport structures such as airports and railway stations, public transport and cultural centres (Çağdaş, 2009). In other words, ABM is a method that leads to various possible outcomes through the development of rule-based decisions. ABM simulations can model the behaviour and interaction outcomes of complex systems of autonomous agents (also known as objects or actors). Examples of agents include people, businesses, animals and plants. Imposed rules force these agents to behave naturally, such as producing, consuming or selling specific resources; shifting their location; in more complex models, agents can evolve, allowing them to learn and adapt to changes in the system they are in (Bonabeau, 2002).

ABM is adaptable in terms of the data and knowledge it can employ, combining qualitative and quantitative data and human and physical data. ABM can therefore create a variety of realistic futures in 'simulated social laboratories' (Ligmann-Zielinska & Jankowski, 2007) where the complexity of human decision-making can be represented, and real-world connections and interactions can be modified. The use of analogue ABM has also emerged as a theme in museum design. As Alessandro, et al. (2013) have pointed out, museum areas are excellent for studying complex human behaviour. Many visitors wander through museum rooms filled with paintings, sculptures and other artefacts in an attempt to use artwork or spatial design to enhance the visitor enjoyment of their visit. Although there is only one main entrance/exit through which visitors interact with their surroundings, many of the rooms contain a variety of paintings and artworks that appeal to visitors in varying degrees. When applied to human-nature interactions, the value of ABM is further enhanced by its ability to model complex information in a meaningful way, encourage interdisciplinary collaboration between scientists (Epstein & Axtell, 1996), and engage policymakers, and planners and community members (Zellner, 2008). Some studies of ABM in art galleries or museums have led researchers to argue that simulation modelling is necessary for analysing pedestrian movement behaviour to predict social and collective behaviour in different contexts. The psychological aspects of human behaviour interacting with the environment are critical points in pedestrian simulation environments. Usability theory refers to a set of concepts and principles derived from psychology, human-computer interaction, and related fields that help designers and developers to create products and services that are easy and intuitive to use. Usability theory can help model the relationship between agents (visitors) and their environment (art galleries or museums) and develop simulations more realistically and accurately. This theory emphasizes the importance of designing products and services that are user-friendly, efficient, and effective, with the goal of improving user satisfaction and performance (Uddin et al., 2021).

Soleymani et al. (2017) used ABM to explore crowd behaviour and social interactions in art galleries. They simulated visitor behaviour in a virtual art gallery to investigate how different design attributes, such as gallery layout and visitor density, affect visitor behaviour. The study found that visitors tended to spend more time in areas with high art density and that there was a social influence on visitor behaviour.

Uddin et al. (2019) applied ABM to understand the impact of design features on visitor behaviour in a museum. They simulated visitor behaviour in different exhibition layouts, and their findings suggested that visitor behaviour changed depending on the exhibition layout and design attributes.

In summary, ABM has shown potential in analysing visitor behaviour in art galleries and museums. However, more research needs to be conducted to measure the impact of design features on visitor behavioural memory.

In this study, the research gap is focused on exploring how different sensory experiences within museums can enhance knowledge transfer and memory retention. This gap is derived from the intersection of three areas of research: the importance of museum space, artifact attributes, and working memory rete

2.6 Conclusion

In this study, the research gap is focused on exploring how different sensory experiences within museums can enhance knowledge transfer and memory retention. This gap is derived from the intersection of three areas of research: the importance of museum space, artifact attributes, and working memory retention. The intersection of these areas highlights the interconnectedness of different factors that contribute to the overall museum experience. Therefore, the focus is on understanding the relationships between these areas and how they can impact visitors' experiences.

One of the key aspects of this study is to analyse sensory behaviour in exhibitions, which includes visual, auditory, olfactory, and taste cues. The research emphasises the importance of multisensory experiences in enriching visitors' experiences, which can lead to improved learning outcomes. Through a careful analysis of the different sensory channels, the study can identify ways in which museums can create more engaging and immersive exhibitions. Another important area of research relevant to the study is memory. The study examines the concept of human memory, influential memory theories, and studies in psychology that can provide insights into how working memory retention can be enhanced in a museum context. The research also explores the role of visiting museums and how the different factors, such as the design of the museum space and the presentation of artifacts, can impact visitors' attention and working memory retention. Finally, the study explores approaches to the agent-based modelling and simulation of human behaviour to understand how visitors interact with exhibitions and navigate the museum space. This can provide insights into the different factors that impact visitors' experiences and can lead to the development of more effective exhibition design strategies.

In summary, the study seeks to identify the different factors that contribute to the overall museum experience and how they can impact visitors' attention and memory retention. By exploring the relationships between sensory experiences, memory, exhibition design, and visitor behaviour, the study can provide valuable insights into how museums can create more engaging and effective exhibitions.

In our forthcoming research, we intend to initiate a series of inquiries or investigations aimed at comprehending the prevailing milieu, visitors, spatial arrangements, and other design elements within British art museums. The aim of this undertaking is to elicit an understanding of the communication strategies employed by curators within these institutions, as well as the behavioural modalities of visitors within the current exhibition contexts.

3. A STUDY OF MULTI SENSORY EXPERIENCES IN UNITED KINGDOM MUSEUMS

3.1 Introduction

Museums are highly valued by society as places of national significance; they vary in size and hold some of the world's most artefacts of curiosity from the past. As we move towards a digital age, the purpose of physical museum spaces to collect, protect, research, communicate, and exhibit materials for research, education, and entertainment (Ahmad et al., 2014) are challenged. In addition to the importance of multi-sensory experiences and interactive exhibits, there are other key factors to consider when designing museum spaces. For example, the physical layout and circulation patterns of exhibitions can impact visitor engagement and satisfaction (Bitgood, 2009). Lighting, soundscapes, and temperature also play a role in creating a positive visitor experience (Smith, 2018). Furthermore, the use of technology, such as augmented reality and virtual reality, can enhance the immersive qualities of museum exhibitions (Ioannidis et al., 2018).

A good museum design can provide satisfying experiences to a wide range of audiences from different cultural backgrounds (Falk and Dierking, 2016). Some researchers focus on the communicative dynamics between humans and exhibitions. Other specialists claim that in various types of museums, such as art, history, and cultural museums, an interaction is an effective way to attract visitors and let them absorb information (Allen, 2005). Several museums appreciate the mix of education, effectiveness, and entertainment of interactive exhibits (Madsen, 2017). It is clear that designing effective museum spaces requires a thoughtful consideration of a wide range of factors beyond just interactivity. Future research should continue to explore the various mechanisms for engaging visitors, such as the use of narrative, emotional design, and user-centre design (Falk and Dierking, 2013). By doing so, museums can continue to evolve and adapt to the changing needs and expectations of visitors in the digital age.

3.2 Literature Review

3.2.1 Museum Exhibition as a Function of the Museum

Museums are regarded by many as essential educational institutions for sustainable human and social development (Burns, 2015; Schade et al., 2019). They have played an important role, especially in reflection on culture, art, and education (Huang, 2019). Moreover, other researchers think that 'Learning experience and knowledge transfer' are aspects that visitors need to consider at exhibitions, this helps to increase the comfort level of the audience (Harada et al., 2018). However, Falk and Dierking (2016) argued that museums are often interpreted as 'educative' and are intended to complement instruction in school. The public can learn from museums, but unlike schools, they are not in a required course but a freely chosen learning environment. Some visitors have no expectations or intentions when visiting a museum; they might have no reason even to visit the museum. The function of the museum as an open education platform is continuously expanding, and visitors can participate based on their personal interests. Museums will pay more attention to the experience and participation of tourists, so future museum design will expand infinitely around the behaviour and experience of tourists (Unal, 2012). To create a more engaging and participatory experience for visitors, museums are implementing various design strategies. For example, the National Museum of Australia has created an exhibition titled "A History of the World in 100 Objects," which allows visitors to interact with digital versions of the objects using their smartphones (Smith, 2015). Similarly, the Museum of Islamic Art in Qatar has designed an interactive space where visitors can explore Islamic art and culture through hands-on activities and immersive installations (Klinkenborg, 2017). The Smithsonian American Art Museum has also incorporated augmented reality technology to enhance visitor engagement with its collections (Marshall, 2017).

These examples demonstrate how museums are expanding their design approach to focus on visitor engagement and participation. By integrating technology and interactive elements, museums can create more memorable and meaningful experiences for visitors.

Many museums have transcended the traditional roles of collection, protection, and research. They are like bridges connecting aesthetics, emotions, and knowledge culture (Harada et al., 2018). They are also places providing visitors with life-related clues and resonances. Visitors can generate new ideas based on their understanding, mastery, analysis, and problems as well as their own experience (Unal, 2012).

The designs of many museums and exhibitions have focused on interactive experiences for visitors that may enrich the knowledge of their visitors and attract new audiences (Levent and Pascual-Leone, 2014). Similarly, scholars believe that 'learning experience and knowledge transfer', defined as the experience of museum visitors in an exhibition (Harada et al., 2018), should receive more attention.

3.2.2 Museum Classification and Field Visits

Museums can be classified in two ways: content and purpose they were established. Classified by content, museums can be identified as:

A. Art museums,
B. Historical museums,
C. Anthropological museums,
D. Natural history museums,
E. Technological museums,
F. Commercial museums.

When classified by purpose, museums can be divided into:

A. National museums,
B. Local, provincial or city museums,
C. College and school museums,
D. Professional or class museums,
E. Museums or cabinets for special research owned by societies or individuals.

Over time, however, the diversity of museums has given people different philosophies and social roles, and people have a new understanding of museums.

According to Parul (2011), the classification of museums is sometimes based on their source of funding (e.g., state, city, private), but this does not clarify the type of museum. In the study of the function of museums, general museums and professional museums have different purposes. They can be divided into five basic types: natural history and natural science, science and technology, history, art and general (Geoffrey, 2019).

3.2.3 Space and Design Elements in the Display Space

3.2.3.1 Environment

Spatial arrangement transforms from a composition of position and behaviour to a pattern of human behaviour and spatial perception, and the user's psychology and behaviour respond to spatial characteristics and activity locations (Zhou et al., 2013). According to the observation of Falk and Dierking (2013), generally, the time visitors spend when visiting an exhibition, whether it is a small museum or a large museum, does not differ. Compared with large one, the arrangement in small-scale museums is more straightforward and there are fewer distracting features, which are relatively limited. People can easily see everything and find interesting the artifacts. Franz (2005) believes that the spatial impression of architecture is based on the human perception structure of architectural tradition. Similarly, the layout of the space allows visitors to experience the exhibition better, and design theory and architectural theory can begin to be used in the framework of the exhibition (Monti and Keene 2016). For example, Zhou et al. (2013) verified the influence of different space layout on visitors, which has four points. First of all, in the exhibition space, the circular space has a strong retention effect on tourists, while the simple space route has a weak attraction for tourists. Secondly, the seatings in the rest area have more obvious effect on the retention of tourists. Therefore, the seating usage of each space is affected by its layout. Then, the linear scene simulation space is rich, and the peak appears in the two booths in the node space, which produces the regional feature, one of its most attractive features. The interactive projection area is a great attraction for visitors. The special lighting environment can affect the behaviour of visitors. Finally, the theme of the exhibition space can effectively guide the flow of people. The design of the node space is very attractive to visitors, especially the endpoint nodes.

3.2.3.2 Design Elements

In a successful design of exhibits, object representation, layout, colour, production, techniques, and visual principles are all in balance. Such components encourage criticism and revision in the viewer (Black, 1950; Belcher, 1991 and Velarde, 2017). The physical experience of the visitor in the display space is multi-dimensional. Besides being with close friends or family members, the control of the environment, such as the temperature of the gallery, the size of the space, or the items and texts that visitors encounter, there is a close sensory connection (Falk and Dierking, 2016).

Design factors are the core of the customer experience. Important feelings and responses are still derived from the design elements (Falk and Dierking, 2016; Forrest, 2013). For exhibition design, the traditional methods can no longer satisfy the public. Objects are the focus of attention for most museums, whether they are paintings, specimens, historical monuments, etc. These things fascinate visitors, and most them are not satisfied with just watching the items but want to feel and manipulate. Some science centres and children's museums have begun to focus on and create more interactive exhibitions, and even some art museums have begun to explore and plan interactive experiences (Falk and Dierking, 2016). User experience and interaction should be considered in the design. Moreover, these can become the central competitive core of economic culture (Wang and Xia, 2019). Falk and Dierking (2016) pointed out that design idioms are the main determinants of the nature and quality of visitors' encounters with objects. Design idioms elicit their instinctual, emotional, aesthetic, and intellectual responses. These design elements can be any display elements: colour, text, space usage, and placement of objects.

3.2.4 Visitor Interaction

In the museum experience model (Falk and Dierking, 2013) shown in Figure 3-1 the museum visitor's experience comprises three parts: physical context, social context, and personal context. The figure suggests that every visitor (i) brings their own personal and social contexts, (ii) is differently affected by the physical context, and (iii) makes different choices, such as which aspect of the context to focus on.

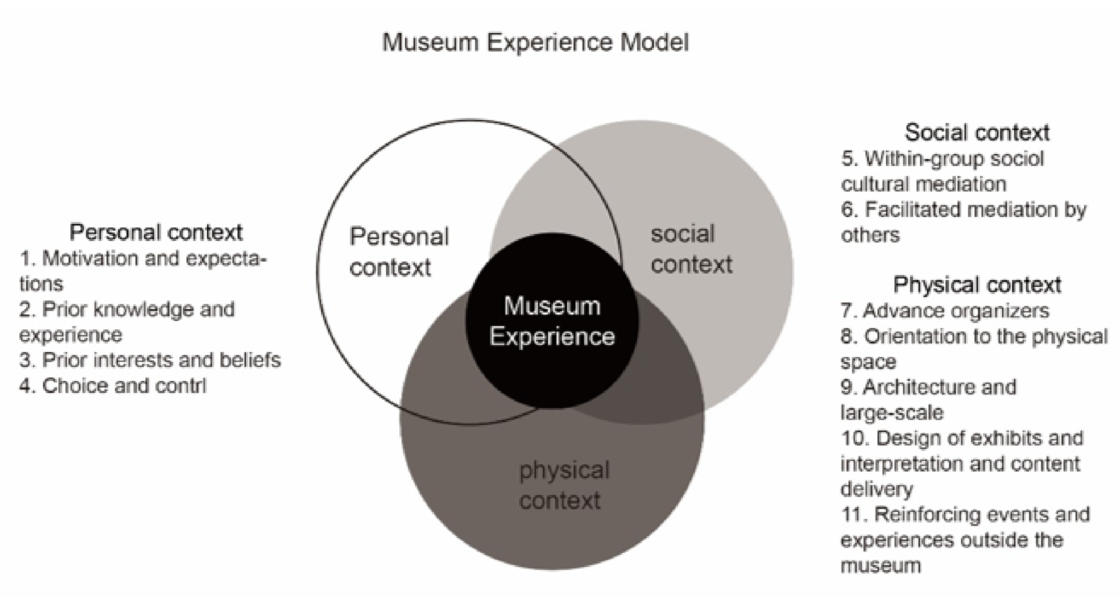


Figure 3-1: Museum experience model (Falk and Dierking, 2013)

Harada et al. (2018) have identified that the relationship between most exhibits and visitors is passive. However, for now, the experience of perceived value represents the visitor's primary evaluation of an exhibition or a museum. They might consider such things as the physical exhibits, interactive exhibits, and five-star services. Perceived value can be increased by the services and interactions in the exhibitions themselves, which trigger good impressions, feelings, perceptions, and associations. Positive emotional resonance is the value of a good exhibition. In the visitor experience service and interaction process, the visitor's value, consciousness and participation motivation can produce a successful visitor behaviour experience, and then lead to different evaluations and behaviours according to their feelings. For example, design an exhibition focusing on narratives and stories to guide or influence the learning and communication abilities of visitors through complex interaction and communication methods (Wang and Xia, 2019). The display space has an impact on the behaviour of visitors; however, the audience is not passive. During the exhibition, everyone interacts with their surroundings, choosing the items they want to interact with or understand, and carefully inspecting them (Gammon, 1999). Even when visitors arrive at an exhibition without knowing what it is about, they actively observe and interact with the displayed objects. For example, visitors expect to read tags, watch videos, and listen to the audio (Falk and Dierking, 2016). At the same time, they further interpret, based on their interactive experience with objects, and connect with their previous experiences and interests. Then they might discuss the exhibition with partners at the social level.

In general, the motivation of visitors to visit museums is caused by various reasons, some of which are for social and entertainment purposes; educational purposes; the purpose of understanding different cultures and pure awe and respect (Falk, 2010). Visitors of different backgrounds can stroll in the museum, no matter what the purpose is, as long as they are interested in these things. Therefore, in the display environment, the behaviour of tourists has always been a matter of concern, and the new multimedia technology has provided new opportunities for museums to make the audience more accepting of the content (Sookhanaphibarn and Thawonmas, 2009). According to research by Falk and Dierking (2016), visitors usually visit the exhibition in four ways. For example, following the route designed by the curator; some people are used to seeing the overall spatial distribution; some people watch the exhibition selectively, while others refuse to follow the route of the exhibition. Visitors usually enter the exhibition based on subjective consciousness and choose intendedly to know things and act in the museum (Falk and Dierking, 2016).

3.2.5 Multi-Sensory Interaction Experience in Museum/Exhibition

Cognition includes human experience. The user experience is a reaction to stimulation through such means as direct observation, participation, hallucination, and enjoyment (Holbrook, 2000). Most objects in exhibitions or museums are inaccessible. Today's art galleries follow the principle of the visual centre, cultivating audiences to watch and think about art from a distance, implicitly using the visual experience as the main sensory component. However, when visitors are told that they can touch the exhibits, they realise that the feeling of touching can increase their deep understanding and memory of real things. The tactile conditions actually provide exciting opportunities to understand the form of artwork. It provides participants with new input about the meaning of the exhibition (Christidou and Pierroux, 2019). Hetherington (2002) believes that touch is a medium to enhance objects and visual senses.

Most museums make sure that galleries have neutral smells and sounds so that visitors can focus on the artworks, but those factors can alter the experience. All the senses -sight, sound, touch, smell, and hearing - are a part of the museum experience (Ucar, 2015). Visitors' experience in the exhibition space is multi-dimensional. Interactions with peers and environmental factors such as lighting, the size of the space, and temperature all have close sensory connections (Falk and Dierking 2016). The benefit of involving more than one sense during a learning experience should not be limited to people with disabilities. A study that analysed the long-term memories of museum visitors showed that their identities, motivations, and learning are inextricably intertwined (Falk, 2010). Sensory experience is a part of cognitive science. Multi-sensory learning is the idea that learning is experienced through all the senses to help to reinforce memory (Stoll Lillard, 2008).

The cognitive process is reflected in the exhibition in the ways that the information received by visitors is processed by their own experience and then feedback to the environment. Visitors with different backgrounds are likely to have different interpretations of the design of the exhibition space, and there are similarities and differences in the processing of information. Even the same person has cognitive biases in different perception environments (Han and Zou, 2018). Cognitive biases can have different effects on perception in different environments, such as in architecture or exhibition settings. Several studies have investigated the impact of cognitive biases in these contexts.

In the field of architecture, one example of a cognitive bias is the availability heuristic, in which individuals rely on readily available information to make judgments about a situation. In a study by Ma et al. (2018), participants were asked to evaluate different apartment floor plans, with some designs featuring balconies and others not. Results showed that participants rated apartments with balconies as more desirable, even when other factors were controlled. This bias can impact the design of buildings and influence the preferences of potential residents or buyers.

In exhibition settings, the framing effect can affect visitors' perceptions of exhibits. A study by Kim and Zhu (2015) found that framing digital exhibits as "interactive" or "non-interactive" influenced visitors' enjoyment and engagement with the exhibit. Visitors showed a greater willingness to explore interactive exhibits, despite no other differences in the exhibits themselves.

In both architecture and exhibition settings, cognitive biases can have significant implications for design and visitor experience. By understanding and addressing these biases, designers can create more effective and engaging spaces.

After Harada et al. (2018) combined the two main areas of the multi-sensory experience and the museum experience, they found seven areas of intersection with other subjects which could connect with these two primary domains (see Figure 3-2). A museum visitor’s experience can be a learning experience. Based on this, museums can use a multi-sensory learning approach to offer the appropriate information to all categories of visitors. They have been developing more and more solutions involving the five senses (Harada et al., 2018). As people walk through museums, they want to learn more about art objects.

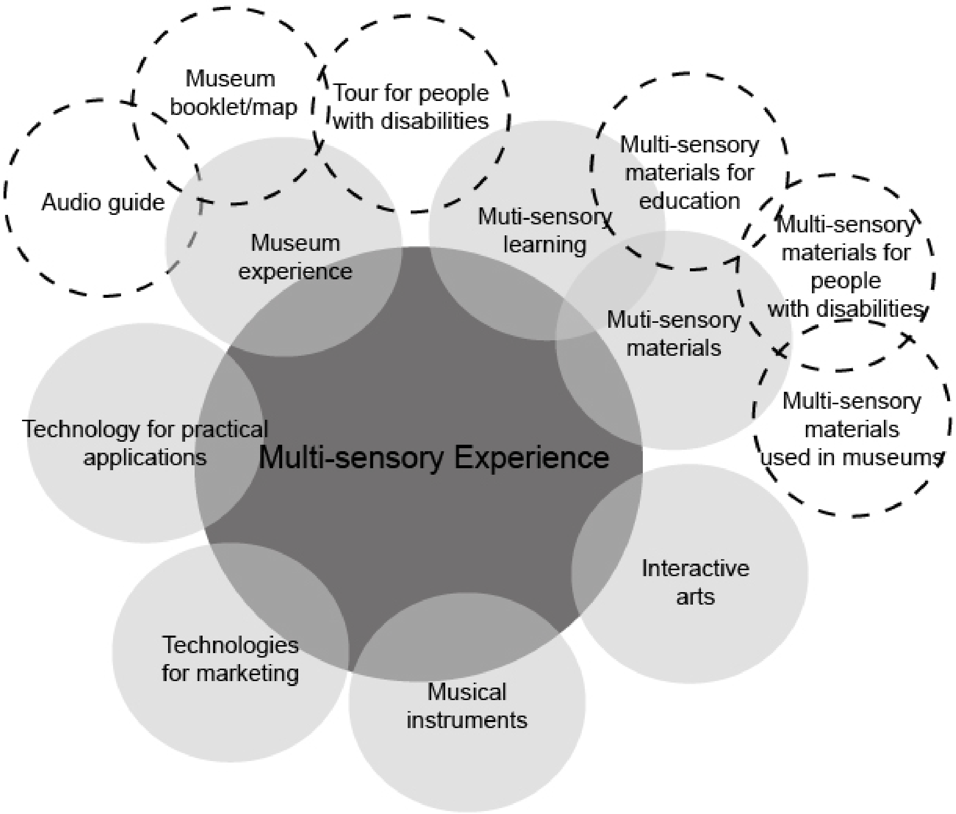
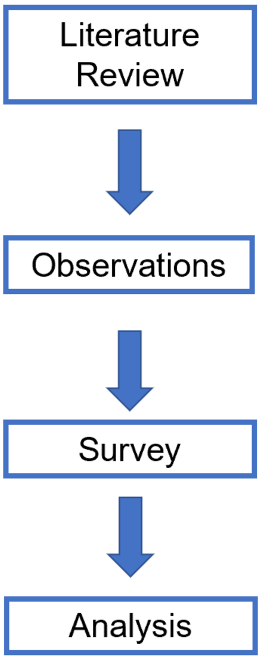


Figure 3-2: Background review (Harada et al., 2018)

3.3 Methodology

For methodology there were 4 progresses in this study to achieve the research objectives: literature review, observation, survey, and analysis (see Figure 3-3). Firstly, based on the literature review, we found a strong correlation between human sensory experience in museum spaces and visitor behaviour. Next, following the literature review, an attempt was made to observe the different types of museums from a bystander's perspective. Then, a questionnaire from a pilot study was used to find out how people thought and felt about a particular exhibition.



1. Discovering the relevance of human sensory experience, museum space and visitor behaviour.
2. Observe 12 museums in London, UK
3. Questionnaires, interviews, targeted questions to find out what visitors really think and do. Observe whether visitor behaviour is consistent with that summarised in the literature review.
4. Derive the results

Figure 3-3: Methodology approach

3.3.1 Observation of 12 Specialised Museums with Exhibitions

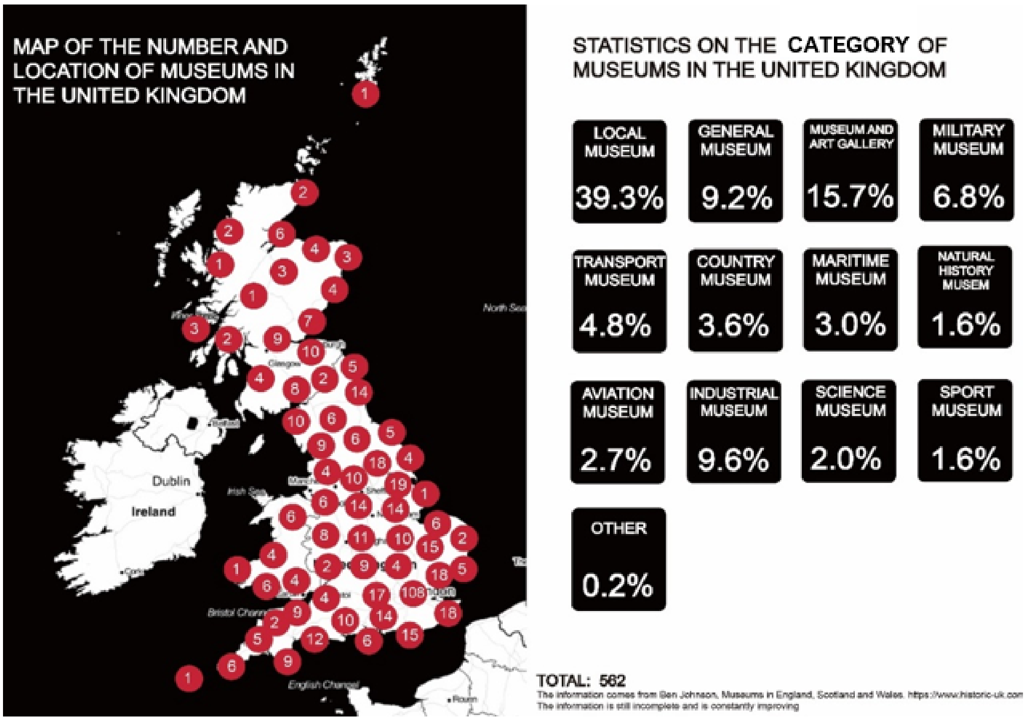
According to estimates by the Museum Association, there are approximately 2,500 museums in the UK. Nearly 1,800 museums have been certified from Museum Association. Registration under the certification scheme shows that the museum has reached nationally recognized standards in terms of management, collection management, and delivery of information and tourist services.

In the process of screening related museums, a travel app called ‘TripAdvisor’ was used to get a general understanding of museums or exhibitions (ShawHong, 2019). For 'TripAdvisor', academics have begun to use the reviews of museums as a source of insight into visitor experience (Alexander et al., 2018), scholars have conducted some data analysis through hundreds of reviews in TripAdvisor, in order to learn about tourists' experiences, attitudes and suggestions.

Finally, based on "TripAdvisor" rankings and reviews, we have chosen 12 museums by voting. They are the Design Museum; Saatchi Gallery; Serpentine Gallery; White Cube; Bank of England; Body Worlds; London Transport Museum; Fan Museum; Foundling Museum; Sherlock Holmes Museum; BIG Food; and

Victoria and Albert (V&A) Childhood. We have avoided the most popular or iconic museums in the public or the country as far as possible, as we wanted to develop our research through the more niche small and medium sized museums.

In the process of trying to master the categories and numbers of the museums in the United Kingdom, we were based on the summary of Historic UK, the geographic location of the entire museum in the UK is drawn (see Figure 3-4; Figure 3-5 and Table 3-1), and an attempt is made to roughly calculate the percentage of museums in each category. Then, most of the museums or exhibitions to be investigated are in London. Therefore, we also performed quantitative statistics and mapping for all museums in London.



(Data gathered by Winnie 2019)

Figure 3-4: Statistics on the category of museums in the United Kingdom

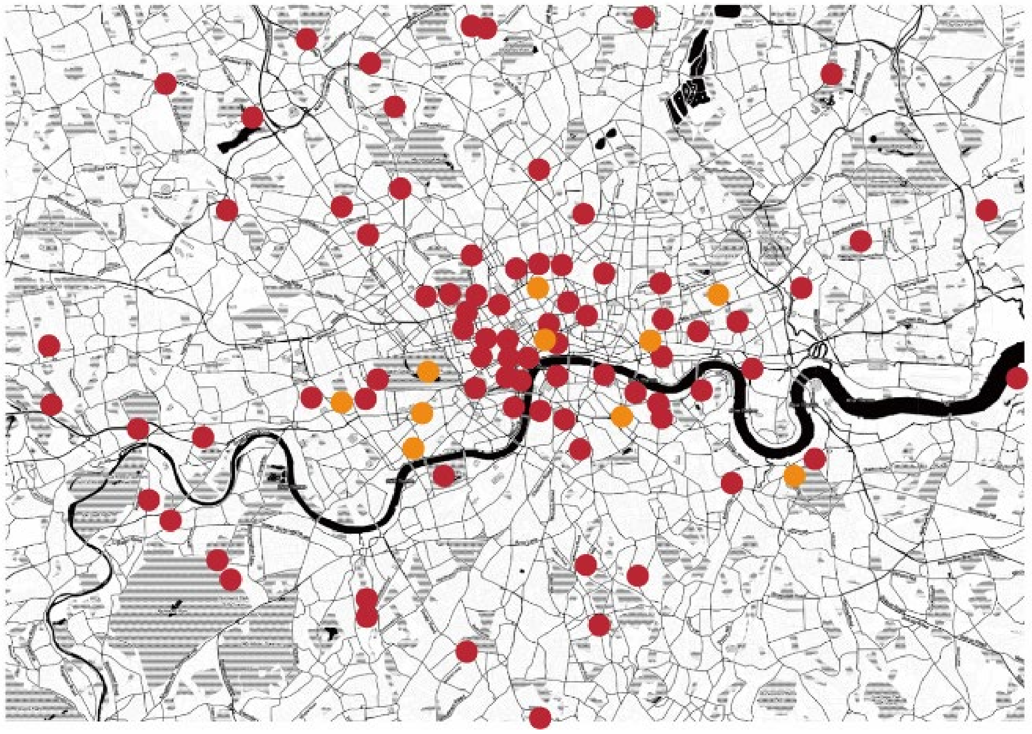


Figure 3-5: Location of museums in the United Kingdom

Table 3-1: Name of museum in London, UK

Local Museum	Local Museum	Art Gallery	General Museum
Horniman Museum & Gardens	Denny Abbey Farmland Museum	Dulwich Picture Gallery	Bank of England Museum, City of London
Brixham Heritage Museum	Enfield Museum	Tate Britain, Westminster	British Museum, Camden
Bentley Priory Museum	London Fire Brigade Museum, Southwark	Tate Liverpool	Jewish Museum London, Camden
Freud Museum London	Museum of Croydon	Tate Modern, Southwark	Royal College of Physicians, Camden
MCC Museum at Lord's Cricket Ground	Museum of London, City of London	Sattchi gallery	The British Library
Kensington Palace, State Apartments	Barnet Museum	The white cube	Wellcome Collection, Camden
Leighton House Museum	Museum of Writing	Mall Galleries	Wesley's Chapel, Museum of Methodism, Islington
House Mill	Stephens Collection	Guildhall Art Gallery	Trade Union Congress (TUC) Library
Museum of London Docklands	Bruce Castle Museum	Barbican Art Gallery	Crystal Palace Museum
Ragged School Museum	Redbridge Museum	Orleans House Gallery	Cartoon Museum
Museum of the the Home (formerly Geffrye Museum of the Home	Headstone Manor and Museum	Camden Arts Centre	Cinema Museum
Museum of Methodism & John Wesley's House	East Surrey Museum	Pump House Gallery	Royal Museums Greenwich
British Red Cross Museum & Archive	Chertsey Museum	Courtauld Gallery	Royal College of Obstetricians and Gynaecologists
Museum of the Order of St John	Whitehall Museum	Hayward Gallery	Hunterian Museum, London
Dr Johnson's House	Museum of Croydon	House of Illustration	Royal London Hospital Archives
Charles Dickens Museum	Wandle Industrial Museum	Serpentine gallery	Royal Pharmaceutical Society Museum
Jewish Museum	Egham Museum	National Portrait Gallery, Westminster	Museum of the Royal Philatelic Society London
Old Operating Theatre Museum and Herb Garret	Spelthorne Museum	Queen's House, Greenwich	Benjamin Franklin House
Golden Hinde	Hampton Court Palace	Victoria and Albert Museum, Kensington, Central London	British Optical Association Museum
HM Tower of London	Elstree & Boreham Wood Museum	Design museum	The Sherlock Holmes Museum
Florence Nightingale Museum	Fan Museum		
Honeywood Museum	Foundling Museum		
Carshalton Water Tower	Kingston Museum and Heritage Service		
Little Holland House	Hogarth's House		
Museum of Wimbledon	Bentley Priory Museum		

3.3.2 Multi-Sensory Transformation in 12 Museums

Research on the potential influence of sensory engagement on museum visitors included a look at how displays at 12 different museums communicate with visitors (see Table 3-2). In most cases, visitors are approached in a more conventional manner through exhibits. There is a broad variety of visual sensory communication options available to visitors to museums, including text guides, media engagement and publications. Virtual reality (VR) is one of the tools that some of them use. These sensory encounters are not as frequent and are confined to the sort of show. Finally, only the twelfth exhibition, "BIG FOOD," displays the interplay between the senses of smell and taste. This is because the exhibition is centred on food.

Table 3-2: A classification of museums using the multi-sensory transform

SENSE TYPE / NO.	VISUAL	AUDITORY	HAPTIC	OLFACTOR	GUSTATOR
1. Design Museum	Text guide Lighting Interaction Media interaction	Audio guide Video display	Commerical model	NONE	NONE
2. Saatchi Gallery	Interaction VR Booklet	Audio guide Video display	Installation art (interact)	NONE	NONE
3. Serpentine Gallery	Video display Screen	Audio guide Video display	NONE	NONE	NONE
4. White Cube	Text guide	Video display	NONE	NONE	NONE
5. Bank of England	Text guide Route guide Video guide	Video display	Touchable replica model Scened design Digital screen	NONE	NONE
6. London Transport Museum	Text guide Booklet Video guide	Video display	Touchable replica model Scened design Digital screen	NONE	NONE
7. V&A Childhood	Text guide	NONE	Scened design	NONE	NONE
8. Body World (Temporary Exhibition)	Text guide Lighting Interaction Media interaction	Audio guide Video display	Touchable replica model Scened design Digital screen	NONE	NONE
9. The Fan Museum	Text guide	Audio guide	NONE	NONE	NONE
10. The Foundling Museum	Lighting Video display Screen	Audio guide Museic auditory	Scened design	NONE	NONE
11. The Sherlock Holmes Museum	Scened design	NONE	Scened design	NONE	NONE
12. Big food (In V&A Museum)	Text guide Lighting Interaction Media interaction	Video display	Installation art (interact) Touchable replica model Scened design Digital screen	Smelling	Food Tasty experiment

The way museums use:

VISUAL:
- Text guide
- Lighting
- Interaction
- Media interaction
- VR Immersive
- Booklet
- Route guide
- Video guide
- Video display
- Screen
- Scened design

AUDITORY
- Audio guide
- Video display
- Museic auditory

HAPTIC
- Commerical model
- Installation art (interact)
- Touchable replica model
- Scened design
- Digital screen

OLFACTOR
- Tasty experiment (Food)

GUSTATOR
- Smelling

3.3.3 Sample and Data Collection

To test the hypothesis of museum memory that more interactive sensory experiences increase knowledge transfer and retention, this study constructs an empirical study. In the study, a questionnaire was designed to collect information about visitors to the New Designer exhibition in London. However, to determine the validity of the information, we first conducted a population-based pilot study.

The New Designer Exhibition is a creative and cooperative platform for fresh design talents, educators, professionals and consumers. The purpose is to connect talented design graduates with businesses looking to bring in new design thinking; buyers looking to source the most innovative craft and design, and aspiring students with the widest range of design courses available to explore. The people who visit this exhibition are very extensive, and people of different backgrounds can visit it.

We chose this exhibition to distribute the questionnaire because our C4D (Centre for Competitive Creative Design) department is a partner of the exhibition, and the central theme of this exhibition was a great design to shape the human experience. The purpose of our research is the same as the curator's purpose, using this unique platform to build a better bridge for designers, users, and creative design objects to communicate and experience.

The classification and analysis of sensory on the multi-sensory transformation matrix were used to analyse and design a set of questions in the questionnaire. The questionnaire consisted of 15 questions for respondents' experience in the viewing process and their personal opinions about the exhibition. A draft of the questionnaire was administered to the centre's staff and to some research students. Their feedback helped us make minor adjustments. The first survey was conducted in July 2019.

Raw data in Appendix B: After the 16 people visited the exhibition separately and filled out the Appendix questionnaires, we put all their answers into a form for review (see Raw data). Then we targeted each question and collected the respondents' answers to summarise and comment on them. Data collection was approved by the Cranfield University Research Ethics System (CURES), 2020. For information on Tables in appendices see Appendix C.

3.4 Participants

There were 16 participants (eight males and eight females) in the observations, including fifteen students and one lecturer. Among the fifteen students, there were nine post-graduate students and six PhDs. For age group, there were 3 participants (17.65%) within 18-24, 11 participants (64.71%) within 25-34, 1 participant (5.88%) within 35-44 and 2 participants (11.76%) within 45-54.

The participants came from design, manufacturing and engineer backgrounds and other professions. From a cultural aspect, they came from various countries, including the China, France, Thailand, the United States, Mexico and the United Kingdom. In this pilot study, although 16 participants represent only a small group of people, they were comprehensively evaluated in the content and experience of the exhibitions from their different perspectives.

3.5 Discussion

Based on each question in the questionnaire, we conducted a sequential analysis of the 11 qualitative questions collected. These questions were divided into 5 aspects to analyse, e.g., personal preferences, the impression of the exhibition, the evaluation from participants, classifying participant’s behaviours and interactive effect.

According to the collection of questions in charts (see Figure 3-6), the majority of respondents indicated that they preferred art, design and history museums or exhibitions, although they were not used to visiting them (and some did not visit them at all).

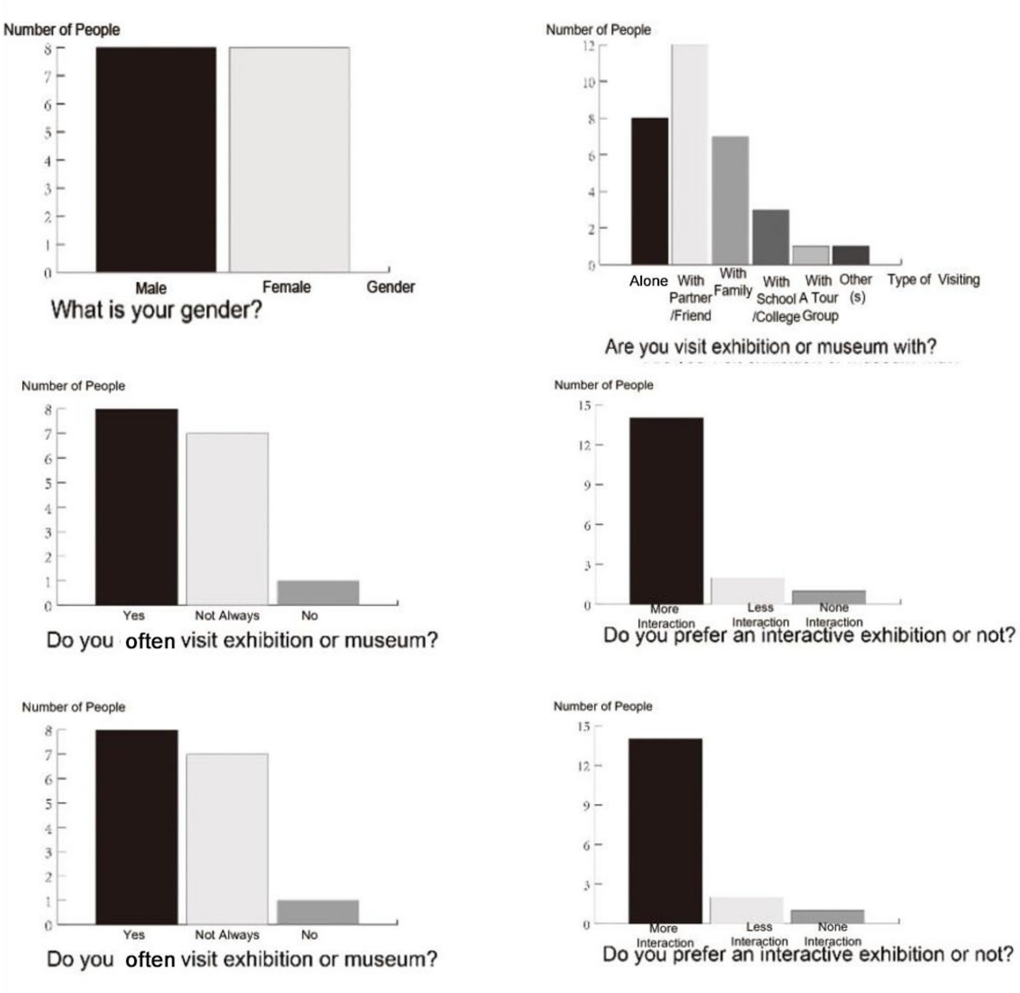


Figure 3-6: The data collection of questions

Many aspects will affect the reasons why people do not visit museums. At the personal level, individual interest, attitudes, and motivations encourage a person to visit the museum. At the social level, the result shows that most of the participants prefer to visit the exhibition with friends and family (see Appendix C). In fact, that a medium exhibition space can bring people closer, and information can be shared better. For those who like to visit the exhibition, they can get abundant feelings through personal experience than the information brought to them by the artifacts itself.

Five participants gave some positive comments about the impressions of exhibition (see Appendix C). Participants believed that they have learned some knowledge in other fields at this exhibition, and after in-depth interaction with products and designers, they have learned more about certain products. Even in the process of communication, you would unexpectedly gain knowledge that you did not know before. However, the comments of other participants are very negative.

The following is their evaluation:

'Very disappointing event, lacking any real innovation or impact in relation to exhibitors and the products that they displayed. Very few inspirational exhibitors, unclear as to what was being displayed and promoted.'

—— Participant NO.1

'It was such a maze, really confusing. I didn't visit a lot of exhibitions but if know for sure that they could have optimised the organisation and the arrangement. Besides that, it was quite interesting to see all the stand with so many items and things displayed.'

—— Participant NO.13

'The way they display the exhibition was good. Besides that, the majority of the project that presented an engineering component was not well design. Some of them were not event tested to see the proper functionality and just focus on the apparent.'

—— Participant NO.12

Through the analysis of participants' comments, the exhibition design needs to be considered from many aspects. First, in terms of social interaction, the close communication between visitors, designers and products helps the interviewees observe and understand the products. From the perspective of space design, some people were confused about the layout of the space and explain that the confusion in the layout of the space did not allow them to concentrate or think. As some researchers have considered, traditional methods cannot meet the public's demand for exhibition space design. User experience and user interaction should be considered in the design, which will become the core competitiveness (Wang and Xia, 2019). In addition, the exhibition design must not only meet the visual requirements, but also meet the requirements of customers, designers, audiences and three stakeholders. Design factors form the core of the customer experience, and their feelings and responses are derived from design elements. Different forms of interaction can give visitors a better experience and deepen their impression of the content, such as space design or other environmental factors (Falk and Dierking, 2013; Forrest, 2014).

Participants were asked about what made them most and least interested in as viewing the exhibition. Many participants stated that they paid more attention to the space, products, interaction, communication, and educational significance. They also pointed out some issues to be improved, such as an unclear information transmission, a lack of communication or interaction with others, an inappropriate text length of exhibition description, the less attractive exhibition, a lack of innovation and chaotic spatial distribution (see Appendix C).

From the responses of questionnaire Q8 and Q9 (see Appendix C), the behaviour of participants who went to the New Designer exhibition could be divided into three types:

1. *Self-thinking - After reading through the text, individuals combine the perception of the real object with the physical experience of the object to ask professional questions. Then they continue to observe.*

2. *Communication - They prefer to communicate directly by spoken language, but this general approach may not impress them.*

3. *Observation -They prefer to explore and solve problems while observing objects.*

In terms of feedback from the questionnaire, these three processes might help visitors to have a deep memory to a certain extent. The method chosen depends on the individual's thinking and interest in the information. Eight visitors were inclined to observe the details of an item and could touch the items while viewing. Five visitors preferred to ask questions about the objects while holding them. These 13 participants have in common that they are eager to touch the objects displayed.

User experience and interaction should be a part of the design. Thirteen respondents believed that more interaction would deepen their exhibition experience and make it easier to connect with the theme and recall later (Appendix C), while the others were not sure about this issue. The impacts of the interaction can be presented in a variety of ways, but still, need to consider which interactions are necessary and which interactions are prone to problems.

3.6 Result

Through the triangulation analysis, we considered four factors of exhibitions and audiences, such as the objective in display space, the audience, the educational aspect, and the quality of the space (see Figure 3-7 and Figure 3-8). First of all, for the exhibition project, the product is not only its design, but also its development, function, impact and innovation for the future. These are the questions that visitors will think about. Second, in terms of user experience, it is easier for visitors to have specific understandings and memories of products through communication, exchange and interaction with artworks. And in the process of discussion will also get different views and opinions. From the comments of participants 10 and 14 (Appendix C), they recalled particular information content, and their use of the product made it seem very interesting and innovative. Most people focused on the future trends of the product and hoped that attending the exhibition can draw inspiration or other knowledge for their future work. Finally, some participants were confused about the requirements of the spatial layout. They found that an overly chaotic space layout interrupted their thinking and prevented them from focusing on individual design projects.

In the questionnaire, participants repeatedly asked questions about achieving space comfort. The comfort level of the spatial layout and the design of the viewing route affected the psychological comfort of the visitors during the formal production process (Appendix C). Good display design and interaction promote good information transmission, visitors thus observe objects more closely and remember content more easily (Monti and Keene, 2016). Achiam et al. (2014) believed that people have a certain familiarity with the places they have experienced. We can perceive space by the texture, geometry or the scale of the space. Some possible actions are inferred from these objects; they are the reflective effects of these objects.

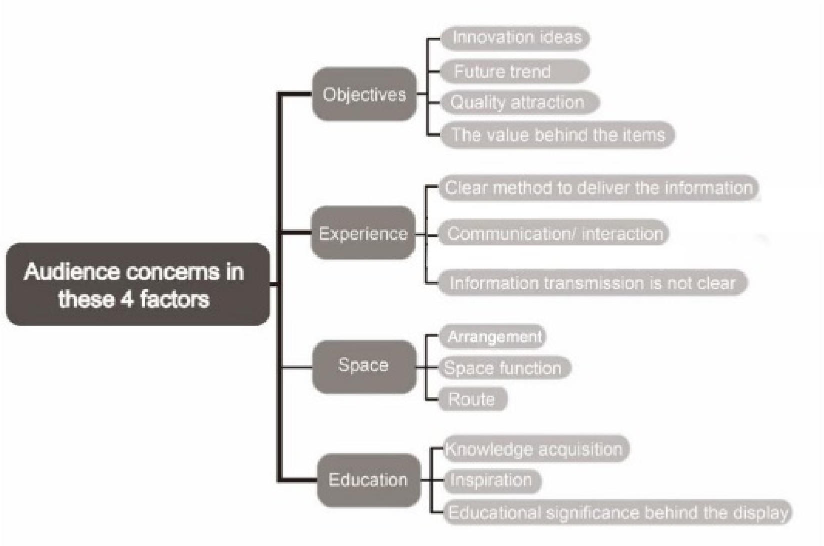


Figure 3-7: A summary of visitors' major concerns in this pilot study

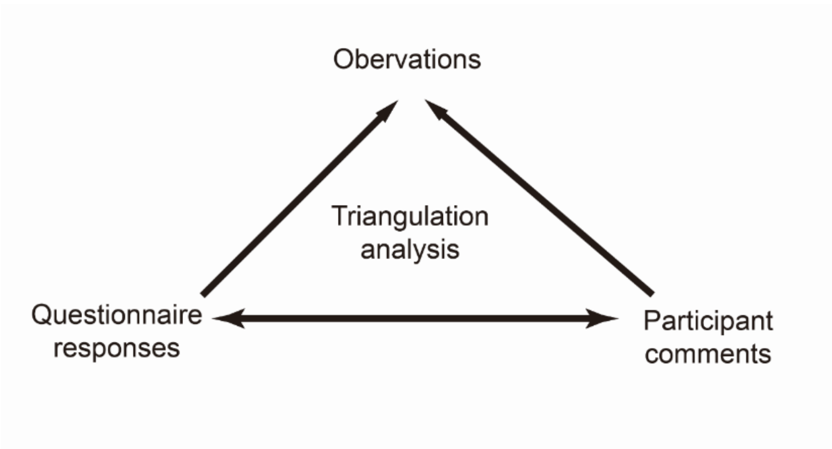


Figure 3-8: The triangulation analysis of three methods.

On the one hand, the definition of the attributes and functions of space can determine the internal content of the participants. On the other hand, space can also be decomposed into meanings that are independent of their function. Emotional space is a phenomenon in which participants' fantasy and emotions are superimposed or projected in real space and its functional, symbolic place (Wineman and Peponis, 2010). The time of memory and the transmission of knowledge can deepen the impression from short-term memory to become long-term memory. In the museum experience, the influence of the environment, such as the design of the exhibition space and interactive exhibits, can evoke the memories of the participants, making it an unforgettable experience (Huang, 2019).

The quality of space in the built environment profoundly affects how we live in it. Our perception of buildings and the built environment influences our physical and emotional experience of our surroundings. It is agreed that sensory stimuli in the built environment affect our feelings and emotions. However, the interrelationship between architecture and the emotions it evokes is not yet fully understood. There are gaps in knowledge at the intersection of architecture, psychology and neuroscience. The relevance of the intersection is gaining traction, but the conclusion on the matter is not straightforward or imminent. Moreover, architects have an innate need to understand how their buildings affect the emotions of their occupants. For example, when designing monuments or sacred buildings, designer emotional states (Eberhard 2008). As Kahn and Brilllembourg said (1992), "One might say that architecture is the deliberate creation of space. It is not a populated area that is prohibited by the customer. It is the creation of space that evokes a sense of proper use."

A growing body of research has explored the impact of neuroscience on the field of architecture, providing designers with new architectural possibilities aimed at influencing people's short - and long-term emotional states. From these studies emerged a branch of science called neuroarchitecture (Banaei et al. 2017), in which modern methods from multiple disciplines are used to study the field of architecture. Many studies have pointed out that the emphasis on measuring emotions is difficult; Quantifying a very subjective emotional experience is inherently a complex task, and subjective methods are considered of limited validity on their own. Eberhard (2009) argues that we can use metaphors to convey some of the emotions we consciously experience, but they are not real experiences of place but rather emphasize the importance of understanding the subconscious neurophysiological responses of experienced emotions. The external stimulus that triggers the emotional response is closely related to the autonomic physiological response. Emotions are reflected in all patterns of human communication, such as word choice, tone of voice, facial expression, gesture behaviour, posture, skin temperature and humidity, breathing, muscle tension, etc. (Picard et al., 2001). The study details how emotion recognition systems are most likely to be accurate when they combine "multiple signals from the user with information about the user's background, situation, goals, and preferences". They argue that "a combination of low-level pattern recognition, high-level reasoning, and natural language processing is likely to provide the best emotional reasoning" (Picard et al. 2001).

Our impression of surroundings is influenced by its entire physical properties (such as brightness, sound, smell, temperature) in a dynamic and interactive manner. The ability to manipulate sensory aspects of the environment so that people feel comfortable or exhibit desired behaviour is to gain interest and social relevance (Jelinčić, Šveb and Stewart, 2021). Many studies have discussed the importance of the sense of movement in historic buildings to evoke the senses, such as the sense of awe. Barrie (1996) argues that surfaces and textures, the scale and distance of entrances, the changes in our vision as we move along routes, slopes and steps, our peripheral vision, and our empathy for the environment (reflected through decoration) are visual spatial factors that affect our emotions and are an important part of the architectural experience. When describing emotions in architecture and other arts, Bruno (2007) discusses the interrelation between "vision" and "site", "movement" and "emotion". This means that studies that focus on emotion and architecture should treat architecture as an experience with a "duration" and a "path of movement." It stems from the notion that perception is action-oriented (Gibson 1966). In our questionnaire, participant emotional response to the spatial layout is also reflected. Some participants put forward negative and positive comments on the spatial layout. For example, one of the participants (no.13) thought the space was chaotic and confusing to the point of not being in the mood for a long viewing. He thinks space should be further optimised. Other participants thought that the layout of the space was fine, and that no matter how many times the same space was repeated, something new would be discovered.

After summarizing each question in the questionnaire separately, we found that qualitative research methods make it difficult to analyse the results of certain problems. For example, people's language is very rich. When analysing a large number of questionnaires, they are free to fill in the remarks and we cannot check them one by one and carry out detailed classification. However, through the pilot study, we can summarize some factors and then classify them as options for the next batch of participants to fill in. This not only saves time and reduces the scope of the options, but also avoids the intervention of many invalid information. Therefore, we believe that the quantitative research method needs to be adopted in the questionnaire. We designed the second questionnaire, which contains confidential questions about the participants' annual income and occupation. This will help distinguish the attitudes and views of visitors to museums according to social class or education level. The museum is an educational place, and also to gather people from various backgrounds, countries, nationalities and cultures. Therefore, after understanding the background of tourists, we may understand the different stages and people’s experience of using museums or exhibitions.

In the second edition of the questionnaire, the questions are specifically related to the participant's experience and the views of the exhibition. Unlike the first questionnaire, we will give participants some fixed options, which makes it easier to determine a specific range in data analysis. In addition, through the specified options, more effective information could be directly analysed.

This pilot study was conducted among 17 participants, which is not fully representative of the experiences and thoughts of visitors. Therefore, in the second questionnaire, we considered requiring more participants to participate in order to obtain comprehensive information. The questionnaire was sent by email and the recipient was asked to forward it to friends and family.

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4. DOWN SELECTION OF METHODOLOGY IN TECHNIQUES

4.1 Introduction

Museums are putting out many solutions to deal with information access and the methods to overcome information access barriers to improve visitor experiences, inspire interest and attract new audiences (Levent & Pascual-Leone, 2014). Multi-sensory solutions seem to have the most important potential for all population groups of individuals, including those with disabilities, the elderly, children, and others. These multi-sensory approaches, which aim to enhance visitors of all types' interactions with works of art, are based on multi-sensory materials (Stoll Lillard, 2008). The experience of visiting a museum is often described as a "learning experience and knowledge transfer". In order to improve visitor museum experience, visitor learning process and information delivery are concerned. Many scholars adopt sensory learning methods, such as immersive interactive experience, tactile experience and taste experience, to solve the development of learning experience and information transmission (Stoll Lillard, 2008). Educationalists have begun using many sensory ways teaching techniques in the classroom to help students learn more deeply and with more motivation from the beginning of training (Montessori, 1912). According to research on sensory learning, multisensory touch helps students to quickly acquire and retain new information or knowledge (Shams & Seitz, 2008). Multi-sensory stimulation also increases the openness of people with disabilities to knowledge (Baker et al., 2001). However, the benefits of multi-sensory experiences need to go beyond impaired people. A study that focused on visitors' long-term memory found that museums' identification, motivation, and learning go hand in hand (Falk, 2010). The museum visitor experience is similar to a learning process, and as such, museums can adopt a multimodal approach to learning that provides all types of visitors with the information they need. Increasingly, multimodal solutions that appeal to all five senses are being developed.

Sensory experiences mainly originate from interactions with multiple senses, but research on working memory is still primarily focused on the study of single senses. According to our research, a multimodal approach to studying working memory is necessary to explore working memory processes, such as preserving memory length and accurate comprehension of operations.

In daily life, people perceive constant information through sight, hearing, smell, taste and touch that affects the internal realm of our perception of the world around us, including the existence of complementary and dynamic interactions and desires between learning, memory, and emotion (Martínez, 2012, Zimbardo et al., 2011). Although our multiple senses perceive the information we receive, psychological research has mainly focused on single-sensory studies. The debate over the psychological experiences derived from these sensory outputs has been intensely explored as we begin to explore multi-sensory performance at different stages (Klemen & Chambers, 2012). For example, in working memory, research has focused on addressing whether the information is represented in a separate modal or domain-specific representation (Baddeley & Hitch, 1974; Schneider & Detweiler, 1988) or in an integrated representation (Cowan, 2001).

The term ‘multi-sensory experience’ describes the simultaneous interplay of messages from several sensory modalities. One feeling may sometimes subtly affect the one we believe to be dominating. Crosstalk between the senses may occur when visual and auditory information conflict, altering what we hear. When a person loses one sense, another may take over. People who are blind, for instance, may adapt their hearing to serve two purposes. People who are blind and deaf may have contact intervention or someone who can translate for them. Each sensory piece of information is impacted individually and uniquely. For some persons with association disorders, the senses violently converge to create a complex world in which words are surrounded by an aura of red, green, or purple, bread has a symphonic scent, and chicken tastes like triangles (Bleicher, 2012). Multi-sensory integration combines data from several sensory modalities into a single multi-sensory experience (Stein et al., 2010). Following Stein et al. (2010), they referred to an object's features as ‘modality-specific’ or ‘cross-modal’, whilst neurological or behavioural processes connected to a single or multiple sensory modalities are referred to as ‘un-sensory’ or ‘multi-sensory’, also they proposed that there were several modality-specific sensory registers that analyse environmental information before it is integrated into a single, modality-independent, or more formally 'schema' perception and stored in STM. This view suggests that short-term storage is an all-purpose adjustment device. This process is referred to as 'working memory' by Atkinson and Shiffrin (1968), as it is thought to be responsible for a variety of tasks, including the selection, manipulation and repetition of learned objects. In contrast to Atkinson and Shiffrin's (1968) concept of domain-independent (i.e., a modal) storage, Baddeley and Hitch (1974) argued that information (e.g., linguistic or geographical data) is retained in its corresponding domain-specific storage through a general control mechanism and central actors in two different subsystems - linguistic loops and visual spatial sketches are managed.

According to data from several domains, there is more interaction in working memory than predicted from a strong domain-specific viewpoint. Baddeley and Hitch (2000) expanded the basic working memory model by including an interpolation buffer to account for the alleged interplay between phonological and visual processes. Baddeley (2000) proposed that the interpolation buffer in this updated model merges memory traces that might come from several senses into a cogent perceptual scene. Druzgal and D'Esposito (2003) and Ranganath et al. (2004) are based on some research on face recognition. In FMRI experiments, they discovered object-specific memory effects for faces in the posterior cingulate gyrus. According to Postle's (2006) theory, brain areas involved in sensory perception are also in charge of temporarily storing sensory data. Working memory will most likely have a unified representation of cross-modal encounters. The spiritual involvement of individuals and the identity connections behind these emotional memories should be given more consideration in contemporary place-making for memory. On the one hand, individuals form social bonds with each other and the wider interested audience. On the other hand, through a series of practical exercises and design research, many resources are combined, and memory places end up becoming catalysts for personal memory, emotion and communication, redefining the concept of memory place-making (Tang, Lu & Yang, 2020). Based on the results of the 50 memory experiments we found, a reliable memory test that utilizes a multi-sensory (at least two-sensory) approach to examining working memory would free memory research from the limitations of a laboratory-based paradigm.

4.2 Memory Method Collection

Fifty short-term and long-term memory tests. Based on the results of the 50 memory experiments we found, a reliable memory test that utilizes a multi-sensory (at least two-sensory) approach for examining working memory would be free memory research from the limitations of a laboratory-based paradigm (Table 4-1) by systematically screening and summarising 150 literature reviews. Meanwhile, the core of these fifty methods is based on Baddeley and Hitch's (1974) concept of working memory theory, the embedded process model, and attentional control in dual- task situations. Based on the results of the 50 memory experiments we found, a reliable memory test that utilizes a multi-sensory (at least two-sensory) approach for examining working memory would free memory research from the limitations of a laboratory-based paradigm.

Table 4-1: Summary of the fifty methods of experiment

No.	Memory Experiment Method
1	The causal luminance disryption
2	Visuo-haptic training system
3	2D patterns and 3D object
4	Digital language memory
5	The science of cycology: Failures to understand how everyday objects work
6	Recognize simple line drawings of common objects using touch or vision
7	Compared the memory span of subjects
8	Visual, haptic and bimodal scene perception: evidence for a unitary
9	Music skill training test
10	Long term memory for a common object
11	Verbal stimuli: words, sentences and quantify the content of memory using a drawing task
12	Drawing as a encoding strategy
13	Free recall of real-world scenes drawing task
14	Large numbers of coloure photographs
15	Test-enhanced learning taking
16	Memory recall the word list
17	Multi-sensory interactive VR space location test
18	The usefulness of multi-sensory educational
19	Tactile stimulation of 32 complex plastic
20	Visual illustration training

No.	Memory Experiment Method
21	Memory recall: visual memory from 2560 photos
22	A corm memory location of 6 types: spatial understanding/ short-term memory/object canvas shape recognition, sequential scanning/ texture and materials
23	Memory recall: look at pictures of 2500
24	The words of memory
25	7 users interacted with a small version of the corona audio space
26	The span of perception experiment
27	Sensory interaction: sound and light
28	Check the memory capacity and retrieval speed of pictures and text
29	A test of using pictures recall and sound of animal's senses to let people recall
30	Memory records in multiple words
31	The stimulation of olfactory system
32	The effect of labels on the recognition and identification of odors
33	The resources of the casual space canvas and speech repetition
34	Memory for common objects: brief intentional study is sufficient to overcome poor recall of US coin features
35	Map cognition experiment and space
36	Language: sentence recall
38	A set of 12 colour photographs of fruits

No.	Memory Experiment Method
39	Words recall: modality effect
40	Language test: 1-20 sentences/word lists and probe words
41	Spatial memory - Egocentric experience
42	The procedure of the experiments: divided into learning and testing phase
43	Familiar objects in visual/haptic crossmodally memory
44	Tactile working memory capacity measured by letter recognition and letter
45	Memory recall for animation effects
46	Spatial location memory in virtual environments
47	Generalizing everyday memory: : signs and handedness
48	Memory recall of visual and auditory words
49	Article content recall: auditory and reading visual conditions
50	Effects of colour on naming and recognition of objects

4.2.1 Pioneering Baddeley and Hitch's (1974) Concept of Working Memory

The fundamental work of Baddeley and Hitch (1974) asserts that something was incorrect with the attractive modal model. Working memory was used in the multicomponent system since several storage methods and processing techniques appeared to be required. Very dissimilar materials, such words to understand and numbers to retain, still interfered with one another, but not as much as if they had completely replaced one another in primary or STM. The benefit of recall for the most recent several items in a 16-word list was unaffected by a contemporaneous digit load, which was peculiar if those last several things in the word list were kept in a short-term store required for digit storage. Concurrent speaking had a considerable influence on recollection of written words but little, if any, effect on recall of spoken words. The findings revealed that a theory with separate devoted modules for diverse functions, as in a nativist viewpoint, was required. These evolved into Baddeley's (1986) model's phonological and visuo-spatial storage.

4.2.2 Embedded-Processes Model

The embedded-processes model is a unitary memory model, and it posits that working memory is an active component of long-term memory and defines broader-to-more specialised hierarchically ordered components (Cowan, 2005) The active part of long-term memory inside the memory system and the focus of attention embedded within activated memory are both parts of the Cowan (2019) information processing model. While a lengthier kind of sensory storage is regarded as one type of active memory, it also includes a perceptual process that results in a brief, initial sensory storage process that stores information in the memory system (along with semantic activation). Similar to how it operated in earlier generations, a central executive aid in managing the focus of attention.

The embedded-processes model was developed in reaction to various perplexing elements of information processing resulting from the modal model, not primarily in response to the Baddeley and Hitch (1974) or Baddeley (1986) models themselves. Following sensory memory, unattended stimuli were removed from further processing, however, people still seemed to notice changes when these filtered-out channels of information changed in their physical characteristics, such as when the lighting suddenly flickered or ignored background noise suddenly changed (Broadbent, 2013). Furthermore, it seemed that the unattended data somehow connected with the long-term memory data, for instance, people occasionally took note when their name appeared on an isolated channel, for instance (Moray, 1959). According to Treisman (1960), the idea that attention attenuates unselected information so that it can still make it to the long-term memory system and perhaps still be remembered as a change. Nevertheless, the idea from Sokolov (1963) that an intelligent creature develops a brain model of the world and then recognises changes to that environment gave Cowan (1988) the impression that a more precise picture of what would occur might be formed. Eliminating the sequential organisation of stores would allow incoming stimuli to establish immediate contact with long-term memory after being viewed, activating the necessary characteristics to the extent that they could be processed (Cowan, 2019). Furthermore, attention may be concentrated on a few recently noticed changes, task-relevant information from the environment, and knowledge that has recently come to mind or been experienced. The knowledge that was the centre of attention in each situation would produce the most well-researched, logical, and insightful understanding of the universe. Several aspects of long-term memory now activated by environmental information, as well as attention's recent focus on deciphering the meaning of stimuli and ideas, may be included in some (but not all) of these. The concept of activated long-term memory information, similar to Hebb's (1949) idea of activated cellular assemblies, will be used to represent working memory in this theoretical framework.

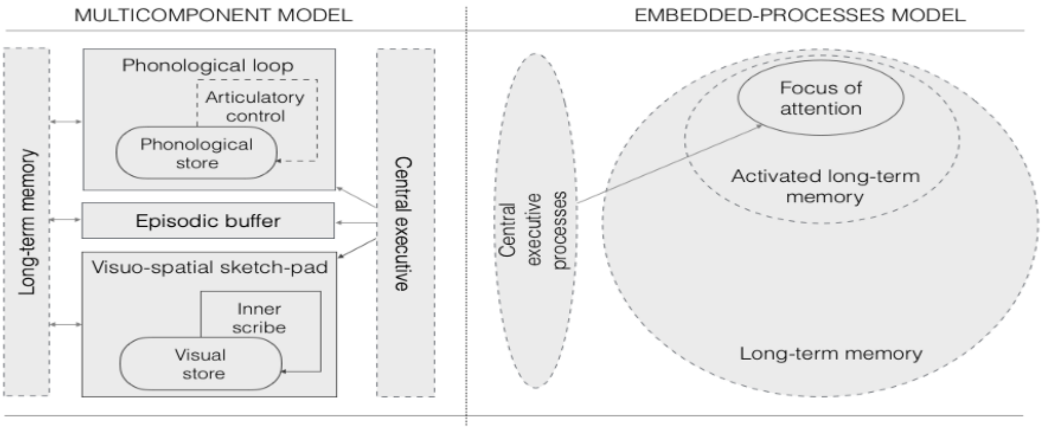


Figure 4-1: Multicomponent model and embedded-processes model (Slana Ozimi, 2020)

Figure 4-1 presents a comparison of multi-component and embedded process working memory models. Working memory representations are established in modality-specific components in the multicomponent model for short-term information storage (phonological loop, visuo-spatial sketchpad, and episodic buffer). The rehearsal processes (articulatory control process, inner scribe), as well as the central executive processes that manage and regulate the information flow in subsidiary systems, enable active preservation of the representations produced in buffer stores. The storage of things in working memory is different in the multicomponent model while intimately linked to the contents of long-term memory. Information in long-term memory can be automatically or deliberately engaged in the embedded-processes paradigm under the supervision of central executive processes. When incoming sensory information is highly salient or is triggered by main executive functions, it becomes part of the focus of attention, allowing for active maintenance. Solid boundaries signify components with limited working memory capacity (Slana Ozimi, 2020).

4.3 Memory Experiment Selection

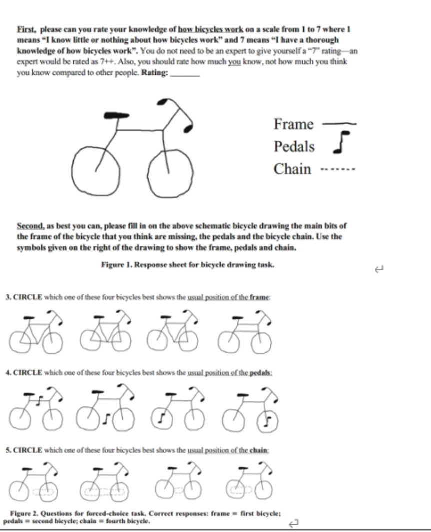
Among the many experiments, we selected the most suitable five experiments (see Table 4-2, Table 4-3, Table 4-4, Table 4-5 & Table 4-6) according to our topic, which are those that involve the sensory (visual, auditory, touch, hearing, tasty and smelling) stimulation of objects, everyday objects, and spatial and intellectual contexts while doing memory experiments). Finally, we conducted a pilot study of the selected experimental methods to observe their feasibility. Currently, we only present the experimental methods that will be involved in our research. For some of the other methods, refer to the summary table of fifty experimental methods in Appendix D.

In Table 4-2, the science of cycology: failures to understand how everyday object work (no. 5) (Lawson, 2006), the researchers' approach was mainly to use questionnaires for data collection. However, the difference is that in the three experiments, the data were collected from ‘non-experts who were not told what the study was testing’, ‘non-experts informed that their functional knowledge was being tested’, and ‘cycling experts who were not told what the study was testing’. This means that when people were objectively assessed on their understanding of the basics of bicycle design, they often made serious mistakes, such as thinking that a chain wound around the front wheel was the same as rear wheel. For cycling experts, more men than women, and for those who saw a real bike during the test, the errors were reduced but not eliminated.

It was made clear that even for frequently encountered and easily perceived information, most people have an incomplete and superficial conceptual understanding of such familiar, everyday objects. This evidence of minimal or even inaccurate causal knowledge is inconsistent with a robust version of explanation-based (or theory-based) categorisation theory.

The model of mapping, questionnaires and interviews used by the researchers in this part of the study can be very well used for quantitative analysis to get participants to respond to specified questions in the context of fixed questions and fixed objects (common objects). It was also possible to get a good idea of what the participants thought and what questions they were asked during the interviews. In addition, in the experiments, experts and non-experts informed that their functional knowledge on the portion being tested was compared with participants' memory factors after training, using common items with some expertise.

Table 4-2: The science of cycology: Failures to understand how everyday object work (no.5)

No.	Method	Picture	Pro	Con	Memory Type
5.	**The science of cycology: failures to understand how everyday object work** Experiment 1: Non-experts who were not told what the study was testing Experiment 2: Non-experts informed that their functional knowledge was being tested Experiment 3: Cycling experts who were not told what the study was testing		Each experiment is exciting and purposeful.		Short-term & Long-term memory Verbal memory Oral recall

In Table 4-3 memory Experiment for common objects: Brief intentional study is sufficient to overcome poor recall of US coin features (no. 34), memory for common objects: brief intentional study is sufficient to overcome poor recall of US coin features (Marmie & Healy, 2004). The researchers explained poor recall of coin features in terms of visual elements. The coin features were then compared by 'accidental contact' and two experiments that deliberately studied US coins to recall their features. It was found that, in conscious studies, high levels of coin feature recall were obtained with short descriptions and remained at the same level after a one-week interval between events. These findings suggest that the poor retention of coin features is due to incidental exposure rather than visual features.

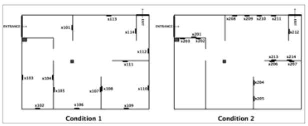
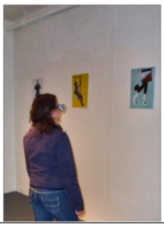
This experiment's methodology tested STM for the item sessions and long-term memory after a one-week interval. However, in the course of comparing intentional and incidental studies, the researchers involved a confounding issue of familiarity. The intentional study utilised an unfamiliar object, whereas the incidental study utilised a familiar object. However, they argue that such confounding is necessary; a purely intentional study of a familiar object cannot be undertaken because such an object may have been subjected to at least some accidental contact. Furthermore, familiar objects may be available during the retention interval; therefore, if familiar objects are given a study, then an accurate assessment of whether memory for these objects is maintained during the delay interval cannot be obtained.

Table 4-3: Memory experiments for common objects: Brief intentional study is sufficient to overcome poor recall of US coin features (no. 34)

No.	Method	Picture	Pro	Con	Memory Type
34.	**Memory for common objects: brief intentional study is sufficient to overcome poor recall of US coin features** Method: Design We used a mixed factorial design with two between-subjects factors—test order condition (penny-first or dime-first) and retention interval group (immediate or delayed)—and one within-subjects factor—coin (penny and dime). Eight participants were in the four subsets defined by the two between-subjects factors. The effects of test order conditions are not considered here.	 Figure 1. The four faces of the Mercury dime and the US Penny	Everyday items Culturally informed background With words, pictures, numbers and meanings. It can be observed with multiple senses.		Written recall Learning training

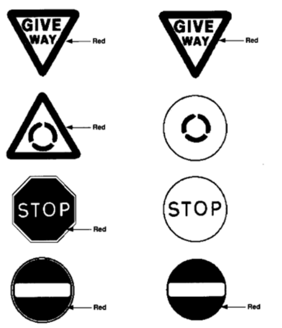
Table 4-4 Map cognition experiment and space layout design 'How the Visitors' Cognitive Engagement Is Driven (but not dictated) by the Visibility and Co-visibility of Art Exhibits' (no. 35) comes closest to the combination of spatial conditions and memory experiments that we need (Krukar & Dalton, 2020). In this study, the researchers explored the effects of the visual features of the exhibits on visitors' attention and memory of the artworks. Attention is recorded using a mobile eye tracker, a sensor technology that detects a person's presence and tracks what they are looking at in real time, usually involving a pair of glasses fitted with a camera, and memory is measured using an accident recognition test immediately after the visit. In this study, we focused on how their memory could be measured using an accident recognition test, in which participants were limited to remembering 14 images and their location in a designed exhibition space for 30 minutes. The exhibition route is not restricted, and participants are free to play and view pictures. At the end of the exhibition, participants placed the images in a given layout based on memory and compared them to the actual picture locations.

Table 4-4: Map cognition experiment and space layout design ‘How the Visitors’ Cognitive Engagement Is Driven (but Not Dictated) by the Visibility and Co-visibility of Art Exhibits’ (no. 35)

No.	Method	Picture	Pro	Con	Memory Type
35.	**Map cognition experiment and space layout design ‘How the Visitors’ Cognitive Engagement Is Driven (but Not Dictated) by the Visibility and Co-visibility of Art Exhibits’** Participants in the designed exhibition time-limited to 30 minutes, 14 pictures and an exploration of space. There is no restriction on any exhibition route; participants are free to play; they just need to read the picture. Text After the exhibition, the participants placed the photo position according to the memories in the given plan. Then compare it with the actual picture position.	Figure 1. Pictures used in the study.   	Very consistent with research, combining spatial locations with memory testing, although actual testing is unlikely to occur in similar art galleries or galleries, other memory tests can be combined. And don't feel bored; just like the game, participants may be more willing to spend time doing it.		Short-term& Long-term memory image memory Space memory Iconic memory

In Table 4-5 generalising everyday memory: signs and handedness (no. 47) investigates the memory of frequently encountered road signs (Martin, 1988). This study's main purpose is to examine whether the left-handed effect in the recall is mediated by motor imagery. And found that one area of everyday memory can be completely generalised to another site, for example, for the study of coins. The material in this study (i.e., gestures and dominant hand) is very indicative of the participants' memory abilities, which can be replicated in No. 5 by ‘non-experts who don't know what the study is testing’, ‘non-experts’. - Experts told respectively that they were testing their functional knowledge’ and ‘drivers who were not told what the study was testing’. And ‘Drivers who were not told what the study was testing’. But the inconvenience was the need to find many participants who could drive.

Table 4-5: Generalising everyday memory: signs and handedness (no. 47)

No.	Method	Picture	Pro	Con	Memory Type
47.	**Generalising everyday memory: signs and handedness** **Memory for frequently encountered road signs was investigated.** **Experiment 1:** Each participant was given a red and a black pen and instructed to draw from memory the current British versions of four different traffic signs. **Experiment 2:** Each participant was tested using a question book-let with successive items printed on separate pages. After the memory probes, part of a more extensive session, handedness was elicited as follows: "Would you describe yourself as left-handed or right-handed? In particular, which hand do you use for drawing?" Participants then completed the handedness questionnaire. **Experiment 3:** Participants were asked to draw any walking figures and digging figures, and the pattern of results was similar to Experiment 2.	 **Figure 1. The four signs used in Experiment 1 (left) and the features recalled by 40% or more of the participants (right).**	1. An excellent memory experience for the driver. 2. For people who don't drive, memory recall can be done after training. 3. Signs for everyday life. 4. Homemade standards can be prepared and will involve a lot of sensory interaction		Short-term& Long-term memory image memory Iconic memory Learning training

In Table 4-6 effects of colour on naming and recognition of objects (no. 50), effects of colour on naming and recognition of objects (Laws & Hunter, 2006); this is probably one of the most original and straightforward methods. In the study, the researchers explored the role of colour in the recognition and naming of everyday objects based on the participants' colour of the objects. The final results showed that colour facilitated but did not inhibit participants' recall of the names of objects and did not affect the memory recognition of objects.

Table 4-6: Effects of colour on naming and recognition of objects (no.50)

No.	Method	Picture	Pro	Con	Memory Type
50.	**Effects of colour on naming and recognition of objects** Two tasks 1. Remembering colours (or colour names) 2. Counting numbers	Material Twelve colours judged to be highly discriminable were selected by the experimenter. Index card. For colour-name conditions, the names of the colours were printed on the corresponding position on the index cards. No colours or colour names were repeated either within a card or between cards. Centred beneath the colours or colour names was a three-digit number which differed from card to card	Easy to remember colours Simple Short-term memory		Short-term& Long-term memory image memory Iconic memory Learning training

5. MULTISENSORY MEMORY EXPERIMENT: THE £1 COIN

5.1 Introduction

The study of memory can be a field that people have been paying attention to for a long time, and its history can be traced back to ancient Greece and Rome (Yates, 2013). Until recently, the direction of memory research has gradually shifted to a new interdisciplinary field and study (Brown et al., 2009). Research on memory is interdisciplinary. Scholars from the humanities and social sciences have turned their attention to sensory memory. This transformation has aroused many insights from researchers on sociality and perceptual culture and has led to the intersection and methods of some new academic fields, such as sensory anthropology, sensory history, sensory sociology, etc (Howes, 2014; Qian & Zhang, 2015).

Our sensory experience is a mixture of multiple senses. Working memory research is mainly focused on a single sensory memory test (Michel, Raquel & Durk, 2017). Moreover, traditional memory and object recognition studies involved objects presented within a single sensory modality (i.e. purely visual or purely auditory objects) (Pawel, Mark & Micah, 2017). For example, when short photos are superimposed on numbers, participants perform arduous visual search tasks involving numbers to divide visual attention. If you do not focus your attention on the picture, then the visual memory will be compromised to increase the similarity between the memorised information and its imagined continuity. Intraub (2008) research shows that memory recall is better for hearing than vision. From the experimental results, that auditory recall is better than visual sentences. It seems that better memory of the most recent words in a sentence does support the regeneration of the rest of the sentence, so the standard modal effect in sentence memory does not apply to the most recent words in the sentence (Allen, Hitch and Baddeley, 2018).

In the experiment of Broadbent, Osborne, Mareschal and Kirkham (2019), it was pointed out that the use of novel category learning tasks examined the prolongation of learning after multi-sensory contact compared with single sensory cues.

Among students, the learning depth of multi-sensory knowledge is greater than that of single-sensory information. Furthermore, multi-sensory tools also have a large impact on education. According to the research of Nairne, Vanarsdall, Joshua and Mindi (2017), compared with objects in a non-contact state, objects in a contact state will make people remember them. An object's animation state is the best prediction for its future retrieval – one of the factors. Delogu et al. (2009) studied how to encode verbal and nonverbal auditory, visual, and audio-visual materials in working memory. Participants were subjected to an instant, continuous recall test to test their visual, auditory or audio-visual stimuli under non-verbal or verbal conditions. Under non-verbal conditions, the stimuli are pictures, environmental sounds, or a combination of both; under verbal conditions, the stimuli are written or spoken or both. The results show that under non-verbal conditions, the series of memories of audio-visual stimuli are higher than those of auditory or visual stimuli. Under verbal conditions, audio-visual materials' recall rates are still higher than the recall rate of visual materials, but there is no difference between the auditory and audio-visual recall rates. The authors also found that participants' memory performance was reduced under verbal and nonverbal conditions. Finally, Delogu et al. (2009) concluded that their experimental working memory model is consistent with Baddeley (2000), in which the presence of the plot buffer integrates information from different modalities and compares it with those from long-term memory. Semantic information is combined. Other studies have also proved the influence of semantic information in long-term memory on visual working memory objects (Olsson & Poom, 2005; Diamantopoulou et al., 2011), indicating that information outside the pure visual domain can affect the work of early visual objects.

The memory of multiple sensory forms provides the perceiver rich information about the surrounding world. It is not just a single sense organ but a cross- tabulation model. (Thompson & Paivio, 1994; Intraub, 2012). One of the first studies to use cross-modal stimuli was done by Thompson and Paivio (1994); they found that compared with modal, audio or visual stimuli, the free recall rate of cross-mode audio-visual stimuli increased. This kind of audio-visual performance is due to the double conditions (audio and visual) and affects each other under picture and audio conditions. Goolkasian and Foos（2005） also found the same situation, the recall rates of cross-mode were higher than the double visual conditions (picture/word) under pictures/spoken word and written/spoken word conditions. Compared to the stimulus provided separately in the old/new object recognition task, the object initially presented as a stimulus that is not related to the task in another sense will be better remembered (Matusz, Wallace & Murray, 2017). The experimental method that follows the dual-task paradigm is usually an experimental method for studying working memory. The experimental method that follows the dual-task paradigm is usually an experimental method for studying working memory. The task experiment is mainly divided into interference tasks and main learning tasks (Picucci, Gyselinck, Piolino, Nicolas & Bosco, 2013). The separation of working memory has been verified by this method. Performance will be reduced if the main task and the interfering task compete for resources from the same working memory component. If they are on different components, the performance of the main task can be maintained. (Baddeley & Andrade, 2000; Farmer, Berman & Fletcher, 1986).

Traditional studies of memory and object recognition involved objects presented within a single sensory modality (i.e. purely visual or purely auditory objects) (Matusz, Wallace & Murray, 2017). In the natural environment settings, traditional research on memory and object recognition is often a multi-sensory model of evaluating and processing objects (Matusz, Wallace and Murray, 2017). Recent studies have shown that people often overestimate their ability to understand familiar things (Rebecaa, 2006). In previous studies, psychological, neurophysiological, and human brain imaging studies have significantly improved people's understanding of cognitive and brain mechanisms that support perception and memory and the interactions they share in everyday situations (Gazzaley & Nobre, 2012). In such daily situations, when we encounter a new person or a new object, the information about them is usually not only conveyed through a feeling. In this multi-sensory situation, it can cause profound behaviour and perception. Changes and these changes are accompanied by remarkable changes in brain activation patterns and participation networks, and the presentation of sensory stimuli in a multi-sensory way will also have a profound impact on our memory. As the test results show, the experimenter only has memories of things processed under auditory-visual conditions and has a relatively weak perception of single sensory conditions (Pawel, Mark & Micah, 2017). Nickerson and Adams (1979) did pioneer work on studying the influence of standard object memory, especially American coin memory. He revealed how rough the memory of ordinary coins is. The experiment proved that most people have severe difficulties recalling the features of the ordinary American penny and placing it correctly on the face, even if a series of features are given.

Our study focuses on challenging and comparing the proportion of single-sensory and multi-sensory memory recall. Memory recall after multi-sensory interaction was conducted by following an experimental approach of a dual-task paradigm. In a field where design and cognitive disciplines intersect, it is hoped that learning about memory will lead to a greater understanding of participants' memory patterns and behaviours and thus to a more detailed understanding of visitor behaviour, memory, etc., in future museum visitor experiences.

5.2 Experiment 1: Generally Understood: Who were not Told What the Study was Testing

5.2.1 Method

To find a better way of online experiments, our experimental methods were inspired by Lawson (2006) and Marmie and Healy (2004). Because of Covid-19, the investigation was unable to convene participants for offline workshops.

All participants conducted this experiment on the £1 coin through questionnaires. At the beginning of the investigation, they need to prepare pens and notebooks. The questionnaire has three sections: personal questions, rate yourself and compulsory selection. In the first personal question section, in addition to some basic questions (age, gender, time in the UK, nationality, which handwriting is preferred), participants were also asked to answer the payment method and the frequency of using cash. Next, in the ‘rate yourself’ section, the participants are asked to estimate their knowledge about the £1 coin in a total of five evaluation levels, from ‘very bad’ to ‘excellent’. They were then asked to try to draw £1 coins relying on their impression on paper (Figure 5-1). Finally, in the compulsory selection (see Figure 5-2), the question will be about all the features of the £1 coin. Each question will give them different options and then choose the correct answer, which checks the drawing error. It is not just because of sketching problems or scoring drawing errors. The survey takes about 4-5 minutes to complete (if they can draw pictures on paper); they are only told that the survey is related to familiar objects in life.

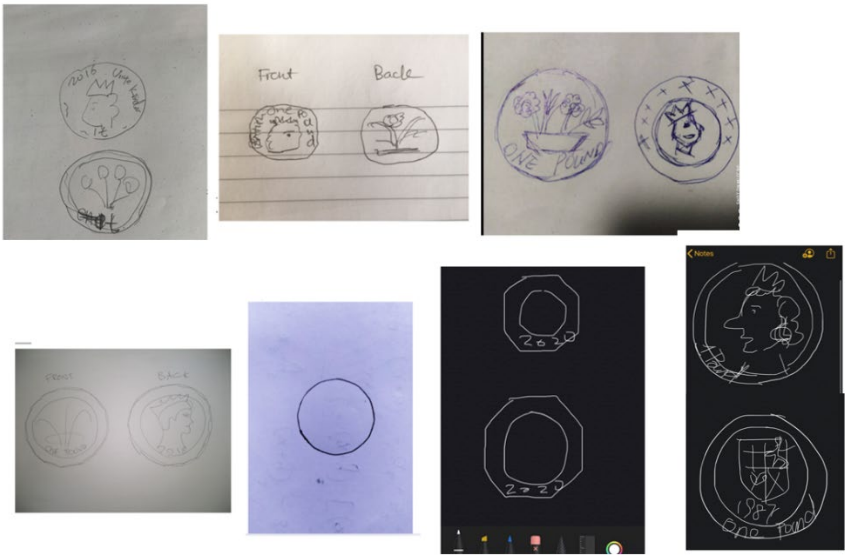


Figure 5-1:A sketch sent by seven of the participants. Only twenty participants sent their sketches to me; this question's effect is not very good by email, but from these twenty drawings, we can see that most people have a vague knowledge of the £1 coin.

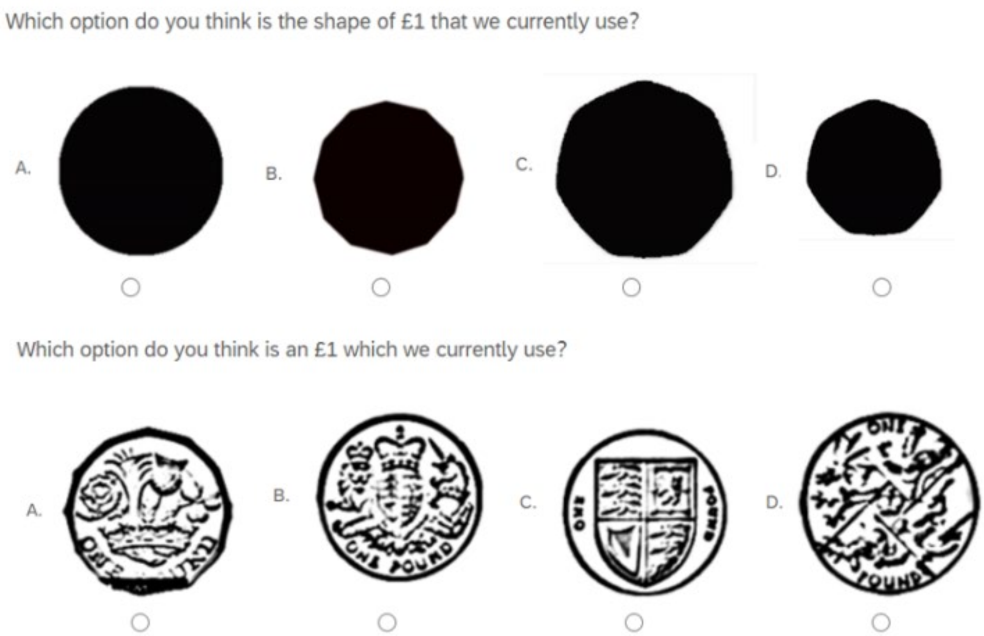


Figure 5-2: Different versions of £1 coins and shapes are added to the options. Allowing participants to choose the correct pattern, which proves that drawing will not have any false impact on memory and will not be confused with hand-drawn memories.

5.2.2 Participant

Two hundred and four participants (62 males and 142 females) were found randomly at Cranfield University. The age of 83.82% comes from between eighteen to forty-four. One hundred ninety-two participants reported being right- handed, and ten participants used left-handed. All the responses were collected online via Qualtrics Survey software; a few sent their drawing sketch to me by email because of the Covid-19 lockdown in the UK.

5.2.3 Result

The experiment was conducted during the lockdown period in the United Kingdom, and the life involved will change, and online shopping became the mainstream. Therefore, to ensure that participants continued using cash or coins during the lockdown period, this study investigated the payment methods. 57.76% of people will use cash and credit cards, 22.55% will be used to using a similar PayPal form of input payment, and 16.18% are the only credit card used. The survey results confirmed that at least 61.27% of the participants would be exposed to the £1 coin in their daily habits; coins are indeed everyday items in life. In the self-assessment of the survey's knowledge of the £1 coin, 55.39% of the participants said they did not know at all, and only 1.96% said they knew very well and knew a lot. Simultaneously, it shows that although most people use these ordinary things every day, they may have an impression, but most of them are very vague and will not over-observe the things themselves. Although only a few participants made drawings in the sketching session, some feedback will be obtained from these participants. For example: ‘I have been in the UK for many years, and I cannot remember what a coin looks like’ or ‘I seem to know its shape, but I am not sure; I need to reconfirm it.

In the last part of the compulsory selection (Table 5-1), participants make a preliminary selection of the £1 coin through pictures and textual options. 65.69% of the participants chose the correct answer by choosing the silver coin's shape. In comparison, 34.31% of the participants still chose the wrong answer for selecting the pattern on the coin, 48.53%, which is close to the average participant's selection error. Questions about the coin's material will be answered incorrectly in more cases, reaching 54.90% of the participants.

Table 5-1: The total number of participants responding to the third section's in four questions. The option 'S&C' in the last 'Material' represents 'Silver and Copper'; 'S&G' represents 'Silver and Gold'.

			Rate your knowledge about UK coin		
Rank	Great	A lot	Medium	A little	Not at all
	2	2	28	59	113
			1 pound shape		
Option	A (ROUND)	B(Correct)	C (6 sides, big size)	D (6 sides, small size)	
	43	134	15	12	
			Pattern		
Option	A(Correct)	B	C	D	
	105	61	28	10	
			Material		
Option	Sliver	Copper	Gold	S&C	S&G (Correct)
	23	13	37	40	92

5.3 Experiment 2: Short-term Memory (Text and Pictures As Media)

5.3.1 Method

In addition to the within-subjects factor of the coin, the between-subjects study time and disturb time were included in the present experiment. The experiment method was the same as experiment 1; all participants must fill out the redesigned survey through Qualtrics online. The redesigned survey is divided into four parts, and the first two parts have the 60s and 30s timing, respectively. In the first part, all participants have the 60s to study a paragraph of text and pictures introducing £1 coin, and then a 30s interference time. During these 30s, other coins information will be displayed in front of participants and read. When the time is over, the participants will answer the seven questions about the £1 coin that has been redesigned. Finally, answer personal questions (gender, age, nationality, etc.).

5.3.2 Participants

Two hundred and twelve participants (83 males, 118 females and 11 people unwilling to tell their gender) were found randomly in Cranfield University and British society. 75.94% of the participants in this experiment are between 18-44 years old, and the others are from different age groups or even older participants, but this does not affect the experiment's results. All the responses were collected online via Qualtrics Survey software because of the Covid-19 lockdown in the UK.

5.3.3 Result

In experiment 2, two methods of text description and image stimulation were used to test participants' STM after fixed learning time and interference time. In the questionnaire, many questions will be related to the characteristics of the 1-pound coin, which have been shown in the text introduction. As shown in Table 5-2, the accuracy of questions 1, 2, 3 and 4 are all above 50%. In general, in this group of experiments, participants' judgment rate did not decrease due to the interference of 30 seconds. The results of the multiple-choice question for question 5 (Table 5-3) cannot be analysed accurately because we provided too many choices (4 out of 8 correct) to make a valid scientific analysis possible. We found that some participants could choose all four options completely correctly or that participants' choices were so scattered among the eight options that they could not be counted effectively, so that the question could not provide correct information.

In this experiment, we found that for STM memory recall of participants, the combination of sensory interaction of language (text) and visual (picture) was effective. Even if we added 30 seconds of interference in the teaching process, it would not affect participants' memory retrieval of text and picture content. Usually, some STM tests are used for education and teaching, as our experimental process is actually a kind of teaching. However, if the visitor interacts with the artifacts in the exhibition, this is actually similar to our experimental process, which also involves the visitor's STM. In addition, in the exhibition, some exhibitions will have a summary of the stages of the exhibition, so that visitors can understand the story of a period through the text. The purpose of our experiment is to test the STM of visitors through the information teaching of text and pictures. Such a setup (experiment) is what visitors would do in an exhibition. The data from this experiment will be compared with the data from subsequent experiments.

Table 5-2: The percentage of questions in Experiment 2. Each question has different choices for the question about the characteristics of the £1 coin in Experiment 2. Finally, we define it as the percentage of people who answered correctly and incorrectly so that the gap can be better seen.

Table 5-3: Questions about the characteristics of the £1 coin in Experiment 2.

Experiment 2		
Initial memory		
Questions	Correct	Incorrect
Q1 - What is its shape?	52.83%	47.17%
Q2 - What is its thickness?	59.91%	40.09%
Q3 - What is its maximum diameter?	58.02%	41.98%
Q4 - What is its colour?	61.79%	38.21%
Q7 - What version of the coin portrait is it?	36.79%	63.21%

Experiment 2				
Initial memory				
Questions	Answer			
Q5 -Which of the following flowers does its own?	League 46.23%	Thistle 57.08%	Shamrock 54.72%	Rose 50.94%
Q6 -Do you know which company made it?	Yes 34.43%	Maybe 50.00%	No 15.57%	

5.4 Experiment 3: Research from STM to Long-term Memory (Video, Audio, and Objects as Media)

5.4.1 Method

In Experiment 2, we tested the comparison of the degree of memory recall of after 60s timed learning through reading and pictures. In this test, the learning time was still reserved, but the time for a video reason was increased to 90s, but this time the media was video, audio and physical media, and the visual, auditory and tactile senses were enabled. The experiment is divided into two stages: the immediate recall of memories, and the second recall of memories to the same participant two weeks later.

At the beginning of the experiment, participants were told in advance to prepare a £1 coin, but were not told why. Then on the day of the test, we download a 1 minute 30 second introductory clip of the 1-pound coin from the Royal Mint's official website. The video is a detailed introduction to the 1-pound coin. After watching the video, participants were allowed to observe the coins in their hands for no longer than 30 seconds. Finally, fill out the same questionnaire as Experiment 2. In the second stage, after two weeks, the participants filled out the same questionnaire as the first experiment and performed a second memory recall. There is no learning time; just answer the questions directly. The questions are basically the same, with individual changes.

5.4.2 Participants

One hundred and thirty-five participants (43 men, 66 women, and 26 people who did not wish to report their gender) were found at Cranfield University and the Milton Keynes Chinese School and Community Centre. In Milton Keynes Chinese School, most of the participants are around 9-18 years old, and some adult students are local Chinese-loving students. This experiment can be roughly divided into two age groups, 9-17 years old and 18-34.

There are two stages in this experiment; it is necessary to investigate and track the participants, so the experiment was finally conducted in certain classes of Cranfield University and Milton Keynes Chinese School. In this way, it can be determined that the experiment's quantitative results are accurate and all come from the same fixed group. Due to the Covid-19 lockdown in the United Kingdom, all responses are collected online through the Qualtrics survey software.

5.4.3 Result

In the third experiment, participants mainly used images, sound and touch to understand the 1-pound coin and then conducted a questionnaire experiment. The progress rate of question response is basically above 50%. Compared with experiment two, the value is higher than that in experiment two. Regarding the fifth question, the recognition of flowers is still not very high, but the correct rate is basically around 50%. Regarding question 6, 60 participants expressed that they knew the name of the company with certainty. Among them, 47 wrote down their answers, and 10 were wrong answers.

After the first memory recall, we performed a second memory recall on the participants two weeks later. In the second experiment, no time was given to participate in any learning, and the same questionnaire was filled out. The only difference was that the question asked whether the participant had carefully observed £1 again after completing the first test. In the end, only 33 participants made observations of £1 again, and the rest of the participants were completely absent from our initial memory in this experiment. Two weeks later, we made a numerical comparison of the memory recall (see Table 5-4 and Table 5-5) and using it as a number or text option; the memory will be relatively attenuated for the memory of similar images, colours, shapes, for example, questions No.1, No.4 and No.5.

Finally, in the process, some participants said: ‘Some of the content has been forgotten; it may be silly’; ‘Some are somewhat impressed, but not sure’; or ‘I remember it’. Even after finishing the work, some participants follow up one after another for a few weeks in the experiment, and some people will replace the coin-related articles and write us to say: ‘Up to now, some problems are still very accurate.

Table 5-4: The percentage of correct answers by participants in the two stages, in experiment 3

	Experiment 3 Initial	Two-weeks later
	Correct	Correct
Q1 - What is its shape?	94.07%	84.44%%
Q2 - What is its thickness?	82.22%	52.59%
Q3 - What is its maximum diameter?	82.96%	54.07%
Q4 - What is its colour?	89.63%	79.06%
Q7 - What version of the coin portrait is it?	60.74%	35.56%

Table 5-5: In experiment 3, the percentage of correct answers by participants in the two stages

Questions	Options	Experiment 3 Initial	Two-weeks later
Q5 -Which of the following flowers does its own?	League	46.23%	25.19%
	Thistle	57.08%	52.59%
	Shamrock	54.72%	54.07%
	Rose	50.94%	50.37%
Q6 -Do you know which company made it?	Yes	44.44%%	27.41%
	Maybe	14.07%%	14.81%
	No	41.48%%	57.78%

5.5 Discussion

Overall, the study objectively measures people's understanding of everyday objects (i.e., £1) through sensory interaction experiences. The reason for using a £1 coin as the medium for the experiment is that we have previously learned information about the history, printing, editions and so on of notes and coins from our observations at the

Bank of England Museum, while the history of the currency is also available on the Royal Mint's website. We believe that £1, as the currency currently in circulation, has the significance of both a museum piece and an everyday object. In the experiment, it was easy for the participant when we asked the participant to prepare a coin. Simultaneously, for the first test, we asked participants to evaluate their knowledge of the coin and select the characteristics of the British pound coin that they deemed appropriate from the prescribed options. Most participants have errors and omissions in their understanding of the coin. It can also be seen from some participants' performances in the picture that the characteristics of the coin part are not prominent. Even for frequently encountered and easy-to-understand information, most people have a rough understanding of the concept of familiar everyday objects. The little or even inaccurate evidence for understanding causality is inconsistent with the robust version of the classification theory based on interpretation (Lawson, 2006). The test in Experiment 1 only gives us a preliminary understanding that most people have a relatively weak knowledge of coins.

In the following experiments, we followed the traditional dual-task paradigm experimental method, which is the experimental method of studying working memory. However, the difference is that we added cross-sensory stimulation conditions. Different from other single-sensory memories (such as vision and hearing), the stimulus recall rate of multi-sensory cross-mode is higher than that of single-sensory. In the second experiment, we mainly used pictures and text to stimulate learning time and interference time, let the participants remember all the coin characteristics, and then immediately through the call. The data shows that more than half of the participants can get correct feedback. Then in Experiment 3, we changed the stimulus conditions to video and audio, and under the same other conditions, the participants were recalled immediately. Comparing the short-term memory data in Experiment 2 and Experiment 3 (see Table 5-6), it is evident that the accuracy of the audio-video-tactile recall in Experiment 3 is higher in the correct answer to each question.

Table 5-6: Comparison of the accuracy of questions in Experiments 2 and 3

	Experiment 2		Experiment 3
		Initial	
	Correct		Correct
Q1 - What is its shape?	52.83%		94.07%
Q2 - What is its thickness?	59.91%		82.22%
Q3 - What is its maximum diameter?	58.02%		82.96%
Q4 - What is its colour?	61.79%		89.63%

Two weeks later, we conducted a second memory recall for the participants who had undergone auditory-visual-tactile stimulation in Experiment 3. We found an interesting phenomenon (see Figure 5-3). The data shows the memory recall after two weeks. The correct rate was higher than the picture-word memory rate in Experiment 2, especially when the questions involved colours, shapes, Etc. The correct rate of memorisation was very high. The picture's meaning is closely related to the content, but people do not remember all the details because they have no practical meaning. A coin is a meaningful object, but the specific details that appear on the coin and the interrelationship or spatial relationship between these details are of great significance (Nickerson & Adams, 1979). People find that people's perceptual memory of everyday objects such as coins and road signs is surprising (Nickerson & Adams, 1979; Martin & Jones, 1998). However, when it comes to memory recall with numbers or words in the options, the results obtained are relatively low or the same. People's memories of specific numbers are not very clear, and this may be because image memory is more stimulating than text memory.

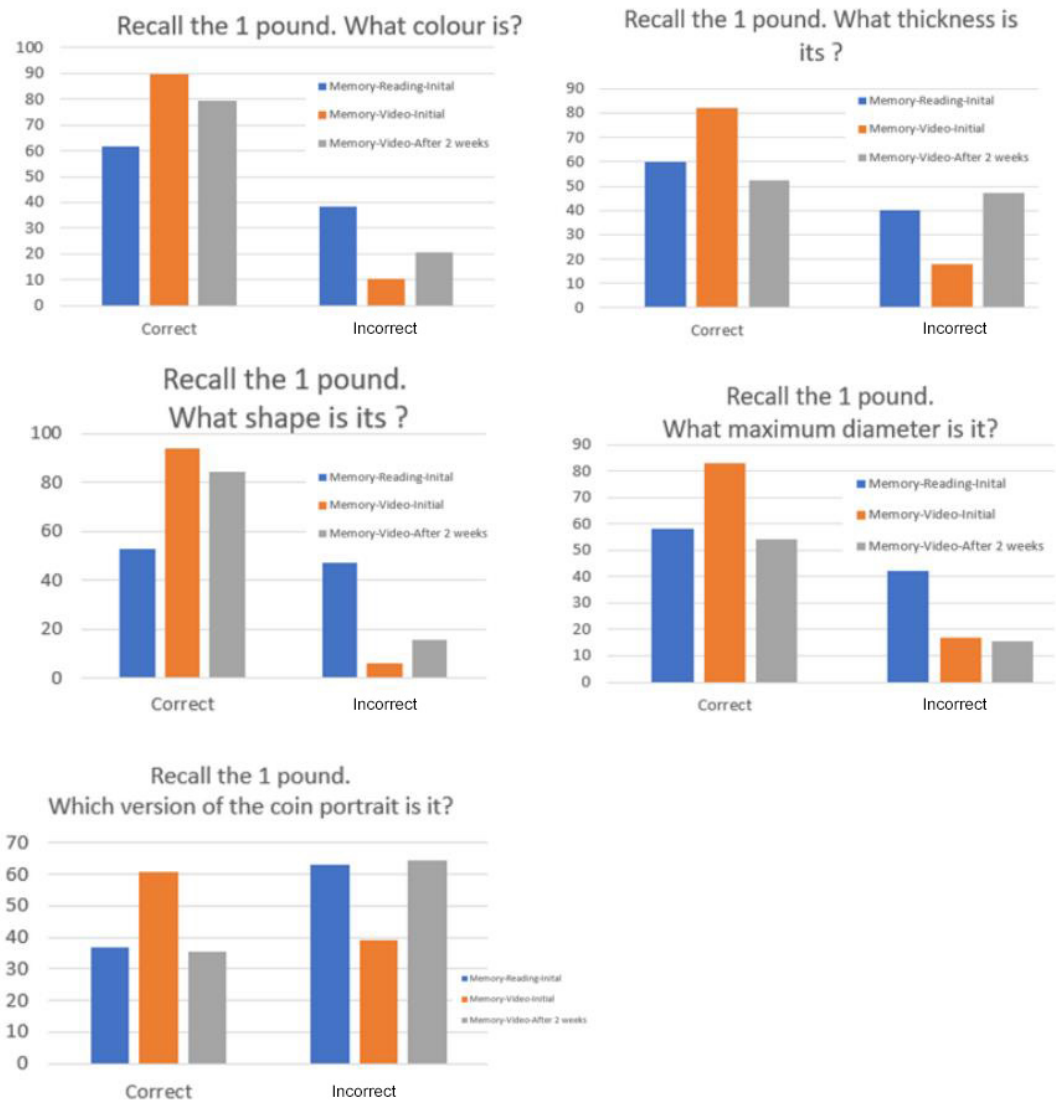


Figure 5-3: Histogram comparison of question correctness

5.6 Result

One hundred and thirty-five participants (43 men, 66 women, and 26 people who did not wish to report their gender) were found at Cranfield University and the Milton Keynes Chinese School and Community Centre. In Milton Keynes Chinese School, most of the participants are around 9-18 years old, and some adult students are local Chinese-loving students. This experiment can be roughly divided into two age groups, 9-17 years old and 18-34. The whole experiment received about 2000 responses, and the results were analysed according to the questionnaire responses of staged experiments. The results showed that multi-sensory interaction evoked more memory for objects than a single visual sense for short-term memory. However, from the perspective of long-term memory, something more visual such as a colour or shape left a strong impression on participants. For more detailed textual descriptions, memories fade over time. This memory experiment was primarily an experimental memory experiment on a museum exhibition space, incorporating the sensory interactions of visitors. Imagine an experiment with a pound coin interacting with one of the artworks in the exhibition. Some artworks in the current exhibition fail to impress the viewer because the exhibit has no physical contact with the viewer. Another phenomenon that is also very interesting is that it is often thought that taking pictures of artwork helps to deepen memory. However, the objects could not remember the specific content of the pictures shortly after viewing them. Visitors did not immediately think of information about a particular exhibit after visiting all the exhibits, but only the most interactive and impressive exhibits during the tour. Although these studies reveal essential discoveries, there are also limitations. Because all memory tests are conducted through the Internet during a particular period, there are three shortcomings. First, it is impossible to determine whether the participants are cautious regarding touch. Observed the object. Second, there is a timing link in the interference phase in Experiment 2, and it is impossible to accurately determine whether the participant has completed the 30-second interference time. Finally, in the first experiment, we hope that participants will draw a pound coin in the form of a drawing.

Studies have shown that painting can improve daily and educational memory (Wammes, Jonker & Fernandes, 2019). However, due to the limited conditions, we could not provide much feedback on the drawing online, so the project did not progress well. The experiment was divided into short-term memory (image-text); Short-term memory (video-audio-text object) and long-term memory (video-audio-text object). During the comparison process, the long-term memory data may be more complete if long-term memory (image-text) is also recorded in experiment 2. This study hopes to add knowledge of cross-cognitive disciplines to museum learning through in-depth research on working memory, in order to create better visitor experience and learning. This study hopes to bring cross-cognitive disciplines into museum knowledge and combine them through the study of working memory, so as to create better visitor experience and learning methods. In future studies, we will continue to focus on visitors' working memory and then study the relationship between visitors' memory recall and exhibits in computer simulation.

6. AGENT- BASED MODEL AND SIMULATION FOR EVALUATING IMPACT OF MUSEUM LAYOUT ON VISITOR MEMORY RETENTION

6.1 Introduction

6.1.1 ABM Technique

At the heart of ABM is the creation and experimentation of intelligence in the environment. This computational approach can enable researchers to create, analyse and experiment with models consisting of agents that interact in the background (Abdou, Hamill & Gilbert, 2012). Agent-based models (ABMs) are composed of agents that interact with one another in a given environment. Agents are discrete components of a programme representing social actors (e.g., persons, organisations such as political parties, or even nation-states). They are designed to respond to the computational environment in which they are situated, which mimics the actual world in which the social actors work.

The benefit of ABM in social research is that it allows researchers to run experiments using models. Experiments on existing systems are not practical or desired in the natural sciences, such as physics and chemistry (e.g., people). An experiment may be repeated numerous times using a computer model and a variety of parameters. Experimenting on a model rather than a natural system is not a novel concept. It is preferable to use a model airplane to test flying under varied situations rather than an actual aircraft (which is expensive to experiment with). Creating an ABM should incorporate the following elements:

First, identify and review existing theories relevant to the ABM research objectives and then incorporate them into the modelling environment as agent attributes or rule inputs. Secondly, the implementation of the model consists of the initialisation of the simulation and subsequent iterations. In these iterations, agents interact with their environment and each other according to predetermined rules. To verify the model, each agent represents a distinct population, organisation, behaviour, geographical environment, or other designated feature when the model is completed. A random number generator distributes the set of

Agents throughout the simulation at the beginning. The Agents' 'VALUE' is then calculated throughout the simulation, with acceptable number intervals defined between the 'VALUE' values, so that through the display and calculation of the data, some simple rules for real-life will emerge (Adamatti, Dimuro and Coelho 2014; Heppenstall et al. 2012). Based on the model, we will further detail the individual application.

6.1.2 The Advantage of ABM

Simulation modelling has six key advantages (AnyLogic in 3 Days, 2018):

1. Simulation models enable us to evaluate systems and identify answers in situations when traditional approaches like analytic calculations and linear programming fail.
2. Developing a simulation model is more straightforward than developing an analytical model after deciding on an abstraction level. The development method is scalable, gradual, and modular.
3. The structure of a simulation model naturally mirrors the system's design.
4. Within the level of abstraction, users may measure values and monitor things in a simulation model and add measurements and statistical analysis at any moment.
5. One of the simulation's important benefits is the ability to play and animate system behaviour in real-time. Demonstrations, verification, and debugging may all benefit from animation.
6. It has higher visualisation and operability, so it is widely used in practical applications. Specifically, ABM can simulate complex systems and interactions in real environments which makes it easier to observe and explore outcomes and impacts under different scenarios. The input and output variables in the model can be displayed more intuitively, facilitating the communication, and understanding between different teams or personnel. Parameter analysis and sensitivity analysis can be carried out more quickly, which is convenient to test and improve the model.

ABM can capture the diverse behaviour and motives of a wide range of social actors and the complex, evolving, and often conflicting interactions between models of agents in the tourism industry. In brief, ABM is a more intuitive means of describing and modelling systems than traditional statistical models, which may often employ so many complicated equations to express occurrences that they become difficult to analyse (Gilbert and Terna, 2000). Users who can comprehend and connect to realistic models are more likely to interact with them and employ their findings. Therefore, this increased realism is critical to ABM's potential as a real-world decision support system. While traditional modelling is abstract, discourages interaction, and may produce only one outcome (which some may interpret as a definitive prediction), ABM provides a flexible alternative that allows users to visualise the impact of input changes, as described by Ligmann-Zielinska and Jankowski (2007).

ABM has been used in various fields such as ecology, transportation planning, and economics (Railsback et al., 2017; Behrens et al., 2018; Foreman et al., 2019). It allows the simulation of the interactions between agents and how these interactions contribute to emergent system-level behaviour. ABM can also be used to test hypothetical scenarios and interventions, such as changes in policy or infrastructure, and observe their impact on the system. ABM has been used to study various phenomena, including the spread of infectious diseases (Epstein, 2002) and the emergence of cooperation in social dilemmas (Axelrod, 1997).

Furthermore, the inputs' kind and specificity are varied, reflecting the model's goal, and might incorporate externalisation not generally included in conventional models. Finally, ABMs can perform under extreme uncertainty, where accurate forecasting of the future is impossible and observational data is scarce. Thus, ABMs have the potential to act as strategy simulators, theory builders, and testers in situations where standard methods of predictive strategy analysis (e.g. Lempert 2002) are ineffective. This competence is crucial in light of the increasingly complex difficulties that the world community is confronting.

6.1.3 The Value of ABM in Human Behaviour

ABM is a computer approach for understanding complex system behaviour by simulating the behaviours of entities inside the system, including how these persons impact and are influenced by their physical and social surroundings.

(Badham et al., 2018). Human behaviour as individuals, small groups, and communities is the focus of various disciplines of study due to its importance in many facets of everyday life. However, including human behaviour into ABMs is a significant difficulty (Kennedy, 2012).

Several research focused on individual behaviour, whether in groups or societies, since it has a direct impact on day-to-day activities. Although this seems to be a straightforward task, modelling such actions in ABM is rather difficult since scientifically examining an individual's behaviour is relatively new. When attempting to mimic human behaviour in ABMs, three obstacles often emerge: understanding people, data, and validation and verification. Human behaviour has been observed for thousands of years, but it has only been researched for two centuries, making it rather uncharted area. However, progress is being made in understanding the characteristics that influence human behaviour, ranging from genetic and historical causes to environmental variables. Human conduct is not random, according to studies. Nonetheless, validating and verifying models addressing human behaviour is challenging, owing to the difficulties in measuring personal qualities and forecasting their conduct (Marzouk & Hassan, 2022).

Humans analyse sensory data about their surroundings, their present conditions, and their recalled past in order to select what course of action to pursue. Humans can detect temperature, curiosity, pleasure, melancholy, wind anger, and other things in addition to the usual five senses (touch, sight, hearing, taste, and smell), which are the only environmental sensors they have (Izard, 2007). Every sensation has a range, a minimum sensitivity, a duration threshold, and more. Humans also have many personality qualities that affect their ideas, behaviours, and emotions. These traits are inherited, seem to be stable throughout life, and account for a significant portion of individual variances (Adolphs, 2006).

Though it may seem obvious to assume that people act in ways that maximise their anticipated feelings, the impact of emotions on decision-making may be more fully examined (Loewenstein & Lerner, 2003). Declarative information, as well as sometimes new procedural knowledge, must be learned in order to change human behaviour. Some systems never forget information, while others have very limited memory for both types of knowledge. Knowledge is maintained for varying lengths of time. Human behavioural systems undoubtedly need some level of memory, but how much memory and how it is formalised depends on the system's intended use. In order to accurately predict an agent's behaviour, a model of rational behaviour must be able to represent knowledge, acquire and recall new information, and then apply it. Emotional, intuitive, and unconscious human behaviour humans are not just logical beings; there are other things that affect how they behave. A decision-making process may be influenced by emotions, intuition, or unconsciousness. These additional decision-making mechanisms may need to be included into ABMs' representations of human behaviour (Kennedy, 2012).

In an ABM, the representation of cognition that drives the behaviour of the person being simulated can have its own internal architecture (Newell, 1990). The ad hoc direct and customised coding of behaviour in a simulated programming language is a relatively simplified approach that uses a random number generator to select among predetermined possible choices, which is in fact inaccessible (Kennedy, 2011). Kennedy (2011) argues that human thoughts, emotions and experiences are not random, that random number generators cannot replace unknown quantities and that the use of random number generators is a false claim for the study of human behaviour.

Rather than relying on random number generators, a better approach would be to directly encode threshold-based rules. This would provide simple behaviours, but they would be interpretable and could approximate human behaviour. Parameters can be transformed so that actions are taken when they are transformed above, below or between thresholds. Using a threshold is equivalent to comparing two values, i.e. the difference between the two values can be compared to the threshold. For example, if the intention is to compare function 1 and function 2, this is equivalent to comparing (function 1 - function 2) with a threshold value of 0.

6.1.4 The Value of AMB in Museums

In recent years, the use of ABM to simulate human behaviour has gradually become a theme in museum design. Nevertheless, early design decisions were incomplete and inherently wrong, which impacted eventual performance (Attia et al., 2012). ABM is considered one of the efficient methods to simulate the design, and to predict human behaviour, for example, in everyday life (Schaumann et al., 2015) and evacuation (Hong & Lee, 2018). However, as most museum buildings are not designed with ABM, visitors face various problems in different environments. For example, some museum departments are not ideal users because either their poor location or certain building parts do not respond to high usage. In architectural design, the human element plays an important role, and the use of multi-intelligent body systems to transfer human movement into the simulated environment is inevitable (Çağdaş, 2009). Academic research has explored complex and ABMiguous design processes (Horvath, 2004), and in recent decades various generic models have been developed for use in general environments (Ulrich & Eppinger, 2011). They have been implemented in many engineering and industrial design schools, but there is still a lack of standardised models in architectural design studios (Hassan et al., 2010; van Dooren et al., 2014; Hong & Lee, 2018). And it has been confirmed that ABM methods can support designers in design evaluation and validation (Shephard et al., 2004). An example of this is crowd flow or emergency evacuation in the construction sector. Researchers have provided a prototype of ABM that uses the concept of usability to simulate the decision-making process during evacuation to model the behaviour of evacuees on underground platforms during routine and emergencies (Uddin et al., 2021). On the other hand, ABM can help designers develop new ways of thinking about building users and incorporate their needs into the design process (Hong et al., 2016). For example, in architectural design, zero-energy building design uses computer-generated information to help make decisions about creating energy-efficient structures (Goldstein & Khan, 2017).

6.1.5 The Potential of ABM Use in Museums

ABM offers many opportunities as a solid and adaptable technology for addressing some of society's most persistent problems, especially multidisciplinary ones. According to Epstein (1999), ABM lets us 'get beyond some artificial constraints that may restrict our knowledge'. Although the study of visitor behaviour has long been a popular topic among museum specialists, most learning approaches still rely on conventional methods such as interviews, group studies, and questionnaires. However, in terms of computer science, AMB research adds a fresh and unique viewpoint to the study of museum visitor behaviour.

Recent research has concentrated on how visitors view exhibits and items in museums based on the display space's architecture. The pedestrian liberty provided by AMB enables the testing of complicated interactive behaviour in a museum setting. The dynamic path of visitors through the various exhibition rooms can be visualised. The visitor's reaction to each sort of artwork and the memory index and happiness with the piece may all be quantified. The amount of time the user spends on the artworks and the visitor's personal memory experience may be affected by the same interaction. Three distinct kinds of exhibition simulations are given in our research. The study's target population is a series of observations on the visitor's recall experience and amount of involvement with the displays. The agent-based model's application area is the conceptual stage of design, which occurs before the application phase but before the completion of all design choices. Using the model on this gap will assist the designers in identifying difficulties and altering the design based on the model's findings at the early design stage (Çağdaş, 2009), helping visitors enhance their interactive experience and increase their memory latency.

ABM is adaptable in terms of the data and knowledge it can employ, combining qualitative and quantitative data and human and physical data. ABM can therefore create a variety of realistic futures in 'simulated social laboratories' (Ligmann-Zielinska & Jankowski, 2007) where the complexity of human decision-making can be represented, and real-world connections and interactions can be modified. The use of analogue ABM has also emerged as a theme in museum design. As Alessandro et al. (2013) have pointed out, museum areas are excellent for studying complex human behaviour. Many visitors wander through museum rooms filled with paintings, sculptures and other artefacts in an attempt to use artwork or spatial design to enhance the visitor enjoyment of their visit. Although there is only one main entrance/exit through which visitors interact with their surroundings, many of the rooms contain a variety of paintings and artworks that appeal to visitors in varying degrees. When applied to human-nature interactions, the value of ABM is further enhanced by its ability to model complex information in a meaningful way, encourage interdisciplinary collaboration between scientists (Epstein & Axtell, 1996), and engage policymakers, and planners and community members (Zellner, 2008). Some studies of ABM in art galleries or museums have led researchers to argue that simulation modelling is necessary for analysing visitor movement behaviour to predict social and collective behaviour in different contexts. The psychological aspects of human behaviour interacting with the environment are critical points in visitor simulation environments. Usability theory refers to a set of concepts and principles derived from psychology, human-computer interaction, and related fields that help designers and developers to create products and services that are easy and intuitive to use. The theory can help model the relationship between agents (visitors) and their environment (art galleries or museums) and develop simulations that are more realistic and accurate. This theory emphasises the importance of designing products and services that are user-friendly, efficient, and effective, with the goal of improving user satisfaction and performance (Uddin et al., 2021).

To further explore the new opportunities and conflicts that brilliant design tools may bring to the design field, we start with the unique museum exhibition space in interior space architectural design. More attention should be paid to the tourists' experience and works of art in pursuing a good space environment design. The visitor's working memory is simulated by drawing from three different categories of exhibition environments. Examine how the new simulation-aided design process differs from the traditional design process (Shi & Yang, 2013), especially in terms of targeting visitor sensory interactions. It believes that practical suggestions can be made through the new simulation-aided design. Raise people's sensitivity to museum theme space information and promote publicity and education. In this context (Wang & Xia, 2019), the practical effects and relative merits of the multi-sensory methods used in this exhibition are analysed from the perspective of communication effects. The familiarity (recall) component is also essential for detecting and recognising sensory descriptors (Saunders et al., 2011).

6.2 Case Study

MK Gallery, UK is selected as a case study (Figure 6-1) to develop, validate and evaluate the proposed ABM. Only the first-floor plan of the gallery is studied in the paper. Initially, the behaviour of the visitors in the room or with the relics was observed, focusing on their route, their behavioural dynamics (such as whether they were spending time chatting or looking at the station or resting), and the ways in which they interacted with the exhibits. In this study, the ABM simulation was conducted on three exhibition layouts and a field experiment on the working memory of images for a third exhibition layout. In the model, the artworks in the exhibitions were categorised into a. Painting; b. Interaction artefact; and c. non-interaction artefact (e.g., Sculpture). The model investigated four general categories of visitors 1. General visitor; 2. Children; 3. Older and 4. Disabled (their details are described in 'Setting and Developing Agent in ABM'). In the working memory experiment, to compare the accuracy of our model data, we selected the photos of 60 artworks in Exhibition 3. An experiment is carried out on the photos to evaluate the capability of recalling the memories of visitors who completed the exhibition through the visual memory of pictures. The data was put into Model Exhibit 3 for model validation.

Figure 6-1: The MK Gallery in Milton Keynes, UK.

6.3 Participants

We assume 200 people and a viewing time of 2 hours for the total number of people. The total number of exhibits depends on the number of products exhibited by the exhibition team. In the picture working memory experiment, 40 participants took part in this experiment, 9 male and 31 female, all of whom completed the questionnaire and interview after viewing Exhibit 3. Based on the type of visitor group in the simulation model, participants are grouped into children group under 18 age (5 people), General Visitor aged between 18-45 (21 people), older group between 46 - over 65 age (11 people), and disabled group (3 people).

6.4 Tool

The ABM tool used in the study is AnyLogic® (www.anylogic.com), which enables crowd movement simulation and the measurement of the agent's memory index in a museum environment. Crowd flow is controlled by walls and a set exhibit route, with a waiting area of a specific size in front of each artwork (e.g., ticket box). Each intelligent body represents a category of people, and its stay is flexible, varying in length depending on the content of the artwork being studied or researched. AnyLogic's user interface provides an intuitive way to create spaces and control the flow of people by adjusting size, time, and destination.

The software is used in many practical applications, integrating advanced simulation techniques. For example, AnyLogic's agent-based simulation modelling helps reposition paintings and display exhibition layouts and provides detailed statistics for each agent/group of agents (both artwork and people in the hall). Moreover, comparing density maps can also determine the cause of crowding in front of specific paintings, allowing designers to use density map observations to solve exhibit path problems. Additionally, AnyLogic's user interface provides an intuitive way to create spaces and control the flow of people by adjusting size, time and destination. In addition to this, it allows customers to test various layouts to find the right one for future exhibitions; the possibility of testing the maximum number of visitors to an exhibition at the same time can be offered to avoid overcrowding problems. This function helps to model safe evacuation plans (AnyLogic in 3 Days).

6.5 Reporting the Model Stress Guidelines

6.5.1 The introduction of the STRESS guidelines

Several studies have used AnyLogic and the STRESS guidelines to improve the reproducibility and reporting of their modelling results. Taylor et al. (2018) applied the STRESS guidelines for a case study of disease modelling, while Onggo and Utomo (2018) used the guidelines to model the dairy supply chain in West Java. Monks et al. (2020) developed a guideline specifically for empirical simulation studies to further promote the use of the STRESS guidelines in simulation studies. These studies not only help to increase the validity and accuracy of their modelling results but also provide a framework for future studies to follow. By incorporating the STRESS guidelines in their modelling process and reporting, researchers can improve the transparency and credibility of their simulation studies.

Other studies have also used AnyLogic and the STRESS guidelines in different domains. For example, Guenno et al. (2016) used AnyLogic and the STRESS guidelines to simulate and analyse the performance of an intermodal container terminal. Meanwhile, Abbasy-Asbagh et al. (2017) used AnyLogic in combination with the STRESS guidelines to investigate the impact of patient flow on hospital performance. Moreover, in order to provide more comprehensive guidelines for simulation studies, Rosenberger et al. (2019) have recently proposed a set of modified STRESS guidelines that specifically address the ethical implications of using digital simulation in scientific research.

Overall, these studies demonstrate the importance of following the STRESS guidelines when using AnyLogic software to ensure transparency and reproducibility of simulation studies. The STRESS guidelines help to ensure that researchers report on critical aspects of their simulation study, such as model inputs, outputs, assumptions, validity, and verification and calibration procedures.

6.5.2 Objectives

This is where we explain the background and rationale for the model, the model outputs and the questions to be answered using the model (Table 6-1). In ABM, we are typically interested in the system-level output that emerges from the interaction between agents. The outputs can be qualitative or quantitative.

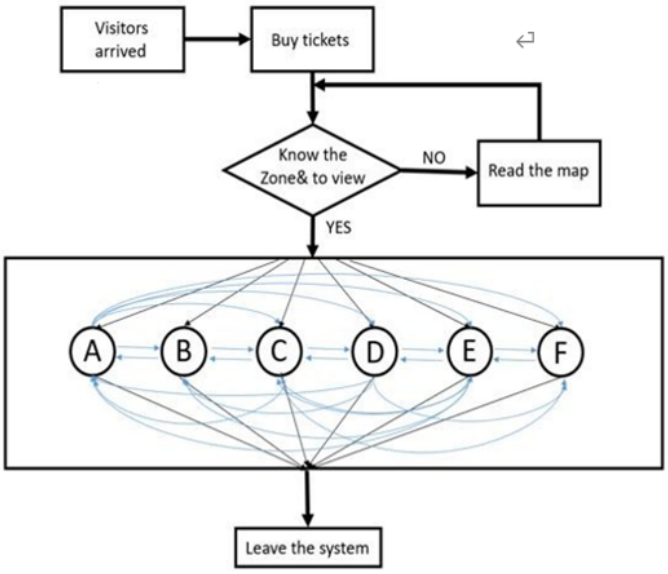
Table 6-1: Model Objectives

Section/subsection	Item	Recommendation
1. Objectives		
Purpose of the model	1.1	In museums, the memory index of visitors is measured, and what changes are made for different categories of exhibits. Interactive exhibits make visitors remember more than non-interactive exhibits, and vice versa
Model Outputs	1.2	Count the number of items in each category remembered by different visitor types
Experimentation Aims	1.3	The purpose of the experiment is to count the number of exhibits that visitors finally remember after visiting the entire exhibition space. At the same time, the number of items remembered in each category was also counted

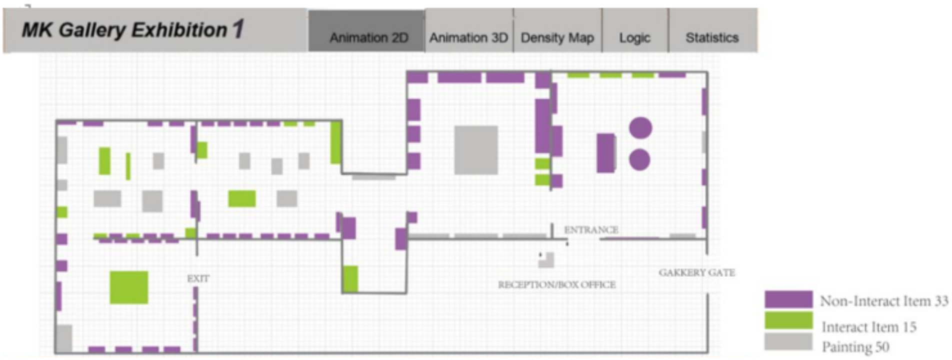
6.5.3 Model Logic

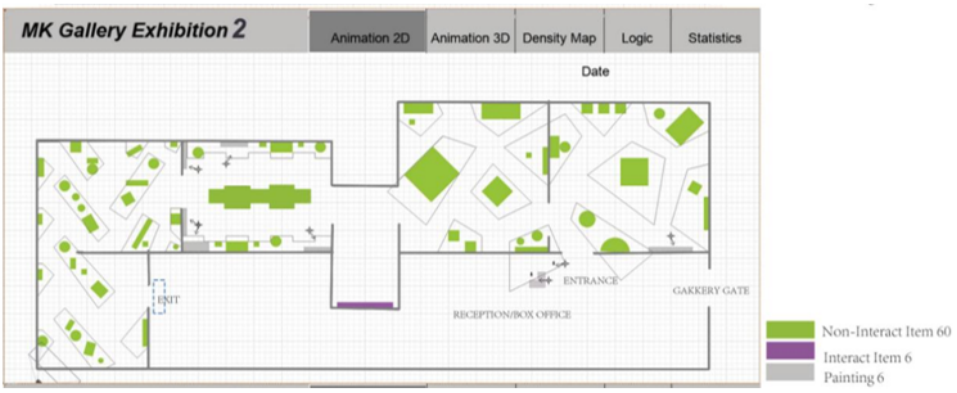
In this section (Table 6-2), we provide the model detail using a suitable conceptual model representation. If the experimentation involves scenarios that use multiple models, then we need to provide the detail for the models. In our model, we simply wanted to know how many artifacts visitors remembered in the simulation after seeing the entire exhibition. Therefore, although we made models of three different exhibitions, we only compared the number of memories of different kinds of artefacts.

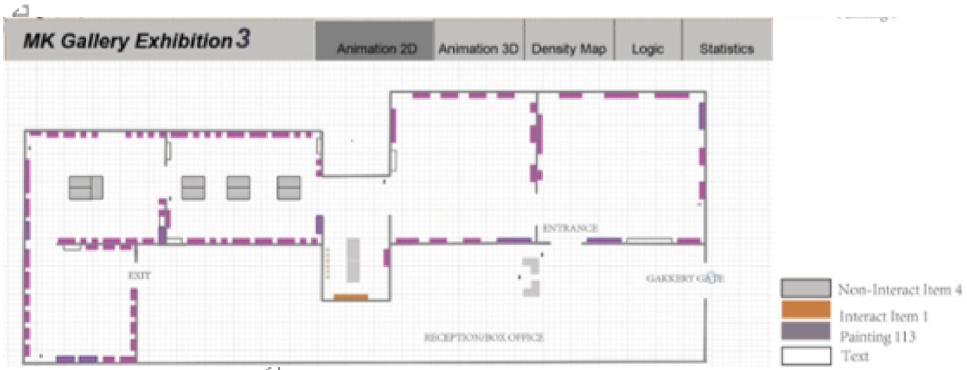
Table 6-2: Model Logic

Section/subsection	Item	Recommendation
2. Logic		
Basic model overview diagram	2.1	The main sequence of the simulation mode could be shown in the flow chart. However, because of Covid-19, the gallery adopted a one-way system of exhibition routes. Therefore, theoretically, during the experiment, visitors were guided by the order of the exhibition space.  **Figure 6-3: The flow chart in a gallery or museum**
Base model logic	2.2	2.2.1 In the model, we first need to make statistics on the type and number of tourists, and then calculate the number of tourists' memorized artifacts according to the calculation method. 2.2.2Calculation method Each Agent has a parameter value. When the parameter value (memory value range) of the visitor is within the parameter value range of the item, the visitor can remember the item, that is, the visitor can remember the item after the visit, and the number of memories for the item +1.
Scenario Logic	2.3	

		We made three models of exhibitions in different periods through MK gallery, namely Exhibition 1 (MK Calling, 2020); Exhibition 2 (Memphis: Plastic Field, 2020-2021) and Exhibition 3 (Laura Knight: A Panoramic View, 2021-2022).
Algorithm	2.4	Not applicable
Components	2.5	2.5.1 Environment 1. The layout of each exhibition uses 2D and 3D animations (pictured). In the floor plan, the gallery has a total of 6 exhibition Spaces, in each space, the color grid represents each kind of artefact, as shown by the logo in the picture. 2. The MK Gallery exhibition consists of six rooms, one entrance and one exit. In the exhibition, the artwork covers paintings, sculptures, and other artworks, thus providing visitors with varying degrees of interest. We chose to test the effectiveness of the ABM approach in modelling the complex emergent behaviour - the memory of a variable number of visitors who attempted to maximize their recall of different types of artworks during their visit experience, using a layout from an actual exhibition. If it encounters an obstacle, it will pass through the side of the obstacle. When it reaches the target point, it wanders around the object until it is time to stay slow. It will then walk to the next object, and after completing the visit of all the objects, the agent will follow the route and leave the system.







2.5.2 Agents

Two categories of agents are set in the model, and each Agent has its own parameter value

Visitor Agents:

1. General Visitor :parameter value-uniform (0.1,0.4)
2. Older: :parameter value- uniform (0.4,0.6)
3. Child (student) parameter value- uniform (0.6,0.8)
4. Others :parameter value - uniform (0.2,0.5)

Artefact Agents:

1. Painting :parameter value- uniform (0.1,0.4)
2. Interaction Item :parameter value- uniform (0.4,0.6)
3. Non- interaction Item :parameter value- uniform (0.6,0.8)

Population:

```
Function :  double tmp = uniform(0,100);
if (tmp<10) {VisitorType = 4;//disable}
else
if (tmp<30) {VisitorType = 3;//child}
else
if (tmp<55) {VisitorType = 2;// older}
else
{VisitorType = 1;//general} ;
```

2.5.3 Agent Interaction:

In order to show the interaction of the agents, I set up the sigmoid function. In other words, the logic is that when more and more people are in the same area to contact an exhibit agent, the attention of artifacts will decrease.

Randomly

Setting:

In setup, we will set this code in each item stay module (delay module)

```
double valueA1 = uniform(0.4,0.6);
if(agent. isRealizeThis(valueA1)){
agent.realizeA ++;} (original)
```

Adding the sigmoid function, it is

```
double valueA1 = uniform(0.4,0.6);
if(agent.isRealizeThis(valueA1*main.SIGMOID(
self.size()))){
agent.realizeA ++;}
```

6.5.4 Data

One way to ensure high-quality simulation outcomes in empirical studies is by adhering to the principle of Garbage-in-garbage-out, which posits that the quality of data plays a significant role. Data collection is a major concern in simulation projects, with Onggo and Hill (2014) identifying it as among the main challenges. As such, modelers may likely spend up to 40% of their project time addressing related issues (Onggo et al., 2013). Thus, documenting the data and data collection process is crucial.

Table 6-3: Model Data

Section/subsection	**Item**	**Recommendation**
3. Data		
Data sources	3.1	Before executing the model, we extracted the parameter setting value requirement (MVR) and memory Value Capacity (MVC) based on a previous memory experiment: recalling an everyday object (£1 coin). MVR is the average reflection value that can be brought to visitors in the museum, and MVC is the reflection value of the memory capacity of the exhibits in the model for different types of visitors. In an experiment recalling a £1 coin, we asked questions about colour, shape, thickness and visual observation patterns that describe the features of the object. The properties of the artworks in the exhibition are then defined based on the results of color, shape, thickness and visual observation patterns. 1. Visual observation parameters of pattern/color - Agent Painting 2. Shape observation parameter - Agent non-Interaction item 3. Thickness observation parameter - Agent Interaction item The model is based on the four Visitor types we observed in our previous museum visitor interaction survey: General Visitor (18-45 years old), Child (under 18 years old), Older (46-64 years old), Disabled (no age group)
Pre-processing	3.2	During the opening of the three exhibitions, I went to MK gallery to make field visits to the

		visitor behavior, such as the exhibition plan, interaction mode, visitor routes, types of exhibits, etc.

Input parameters	3.3	Agent Person which is used to calculate the distribution of different kinds of people in the simulation.
		Model parameter:
		● Visitor Type
		● attentionParameter
		
		● **Function-CalcuType**
		double tmp = uniform(0,100);
		if (tmp<10){
		VisitorType = 4;//disable
		}else if(tmp<30){
		VisitorType = 3;//child
		}else if(tmp<55){
		VisitorType = 2;// older
		}else{
		VisitorType = 1;//generalVisito}
		
		● **Function-CalcuAttentionPara**
		if(VisitorType==1){
		attentionParameter=uniform(0.1, 0.4);
		}// general visitor
		if(VisitorType==2){
		attentionParameter=uniform(0.4, 0.6);
		}//OLDER
		if(VisitorType==3){
		attentionParameter=uniform(0.6, 0.8);
		}//child
		if(VisitorType==4){
		attentionParameter=uniform(0.2, 0.5);
		}//DISABLE
		● RealizeA
		● RealizeB
		● RealizeC
		These represent three kinds of artefact paintings, non-interaion item and interaction item
		
		● **Function- isRealizeThis**
		if(attentionParameter>artifactPara){
		return true;}
		else{
		return false;}

Assumption	3.4	The tourist routes are randomly distributed, the exhibition time of each type of artifact is not the same, and the tourist movement speed is the same.

6.5.5 Experimentation

These settings (Table 6-4) in which the model is used to generate outputs are described in this section.

Table 6-4: Model Experimentation

Section/subsection	Item	Recommendation
4.Experimentation		
Initialisation	4.1	Most of the input parameters (item 2.5) are set using the user interface, and the calculation logic is also described in item 3.3
Run length	4.2	2 hours
Estimation approach	4.3	The model is stochastic.

6.5.6 Implementation

This section (Table 6-5) provides information about the execution platform which is important due to the lack of backward compatibility in some software tools.

Table 6-5: Model Implementation

Section/subsection	Item	Recommendation
5. Implementation		
Software or programming language	5.1	Anylogic
Random sampling	5.2	Built-in functions from Anylogic
Model execution	5.3	ABM model is using fixed-time steps.

System specification	5.4	Not relevant

6.5.7 Code Access

Open science initiative aims to make research accessible to wider audience, especially publicly funded research. We expect that more simulation models will be accessible. Our code is not ready for public access at the time of writing. When it is ready, we will upload it to the Open ABM platform.

Validation of model, a random number generator distributes the set of Agent throughout the simulation at the beginning. The Agents' 'VALUE' is then calculated throughout the simulation, with acceptable number intervals defined between the 'VALUE' values, so that through the display and calculation of the data, some simple rules for real-life will emerge (Adamatti, 2014; Heppenstall et al. 2012). Based on the model, we will further detail the individual application.

6.6 Result and Discussion

Our ABM was tested on three different exhibition layouts (between 2020 and 2022) at MK Gallery with deterministic and stochastic parameter values. This testing aims to verify our model by comparing the simulation results and the real data.

6.6.1 Deterministic Data

Firstly, we used deterministic data to validate the accuracy of the proposed ABM. As shown in Figure 6-2 , the parameter values are fixed based on the results from the memory1-pound experiment. As the minimum and maximum values are not meaningful, we ended up just taking the average value to see the results. For example, in Exhibition 1, 98 regular visitors remembered 1407 exhibits in 2 hours of viewing time, an average of 14 exhibits per person out of a total of 98 exhibits; 51 older people remembered an average of 13 exhibits per person; 45 young children remembered an average of 17 exhibits per person, and disabled people remembered 15 exhibits per person. In Exhibition 2, visitors of all types could only remember an average of 1 out of 72 exhibits. In Exhibition 3, out of 118 exhibits, the average visitor, the elderly and the disabled type of agent could only remember one exhibit.

In comparison, children could remember an average of seven exhibits. The conclusions we have drawn so far are not informative because of the lack of randomness in our model. In order to better fit the purpose of real human behaviour, MVR and MVC are scoped to ensure that each person experiences each artefact differently so that the randomness of real behaviour is better reflected.

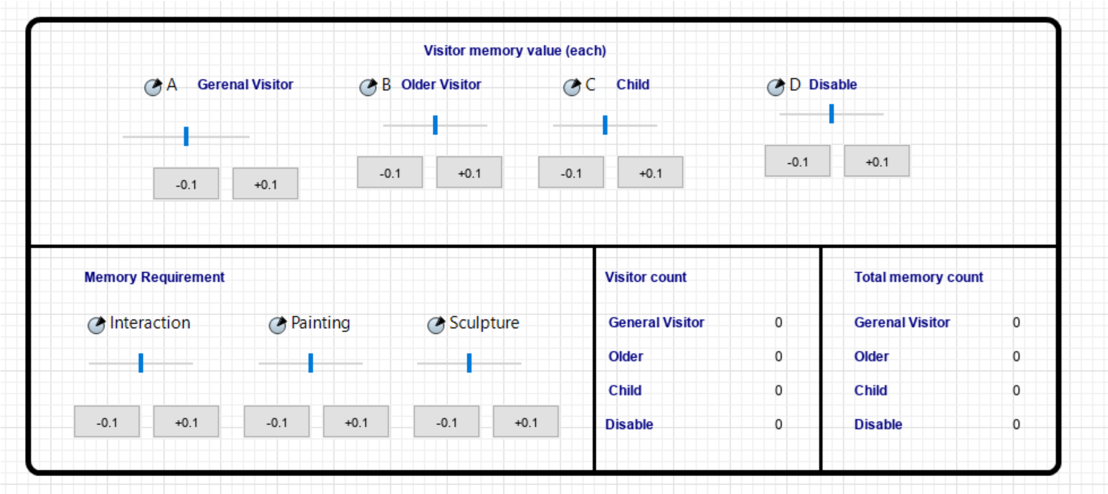


Figure 6-2: A user interface for inputs and outputs of the ABM

6.6.2 Stochastic Data

In the new simulation, agents follow a probability distribution of different values. For example, in the parameter setting section, MVR and MVC are generated based on a uniform distribution between two numbers, representing the randomness of the data. The simulation (Figure 6-5) represents, for example, the average in Exhibition 1, with 93% of the items remembered by the average visitor. The model is simulated 100 times and its average value is taken at last. The simulation is carried out among 200 spectators. As can be seen from Figure 6-5, on the exhition1, the highest memory rate of the general audience is as high as 1.37%, which is obviously too high, but it also shows that the memory recall rate of the general audience is relatively high. This indicates that, on average, each person's memory recalls more than one artefact or even some may have recalled zero, others two or three, etc. In addition, in conjunction with Table 6-3, it can be seen that the rate of interactive artworks was higher in Exhibition 1 than in the other two exhibitions, which also suggests that the number of memory recalls increased in most cases depending on the interactive nature of the curatorial approach.

The simulation results for three exhibition layouts show that the General Visitor has a higher proportion of memory values in Exhibition 1 than the other types of people, followed by older people who have a higher proportion of memory values in Exhibitions 2 and 3. This finding confirms that general visitors (e.g., the family group) usually follow the marked route to the exhibition, mainly for leisure entertainment rather than to learn about the exhibition's content. Then, older visitors can recall objects when viewing the exhibition, as they engage with each exhibition content, usually viewing some artworks with a learning attitude and spending relatively more time than the general visitors (Han and Zou, 2018). Next, the disabled and finally the children and adolescents age group had the lowest memory. In Serrell's (1997) study of the duration time of visitors in the exhibition, it was shown that visitors typically spend less than 20 minutes in an exhibition, regardless of its subject matter or size, and that most mental concentration states cannot be sustained for an extended period of concentration. There is a pattern to visitor visitation behaviour, with visitors essentially spending relatively more time dwelling on more elements and engaging with more of what the exhibition offers.

The visitor's experience is not made up of what the exhibition offers but of what they choose to attend.

The results also suggest that for adults, there is a large degree of memory recall of the exhibition content after the exhibition. However, it can be assumed that the child or adolescent age group has almost no recollection of the artworks in the exhibition hall that was not interactive after viewing the exhibition. Unless there was an interactive installation about a more interactive experience, such as in Model Exhibition 1, the level of memory for the child or teenage age group was higher than the data from the other two exhibitions, as Exhibition 1 had more interactive artworks, so children would be more likely to remember some of the more interactive exhibits. The phenomenon of high memory in children confirms our hypothesis that one of the most salient ways of acquiring new knowledge is through interaction with and observation of other people (Gerson & Meyer, 2021). The average values in Table 6-8 further confirm our hypothesis that more interactive exhibitions increase people's memory levels. From a design perspective, the combination of exhibition elements impacts visitor flow, dwell, and time spent (Yalowitz & Bronnenkant, 2009). By looking at the sensitivity of different visitors to the memory of different objects, we can see that the value of the interactive objects is higher than the other objects in the three categories of exhibits. The value of interactable objects may suggest that any artwork with which a visitor interacts will be largely memorable, closely followed by the category of paintings. For example, after years of systematically collecting time and tracking data, the Monterey Bay Aquarium has found different patterns in the way visitors use different types of elements (Yalowitz, 2004; Yalowitz & Ferguson, 2006).

Across multiple thematic exhibits, the percentage of visitors attending specific exhibits consistently showed the same order, from highest to lowest: large live animal tanks, medium live animal tanks, small live animal tanks, hands-on/interactive exhibits, videos, objects, and plain text. Although the information is less surprising, it enables the exhibit team to configure the exhibit to reduce visitor congestion and maximise traffic. It helps to set realistic expectations for specific types of exhibits. It also allows the exhibition team to experiment with new approaches to the exhibition and understand how these changes affect visitor behaviour patterns. For example, in 'Sharks: Myths and Mysteries', the exhibition incorporates many cultural elements and emphasises the use of technology. The physical theatre exhibition on the story of Stringray's mother (Yalowitz & Bronnenkant，2009) was very well used, and this is the first time since the data was collected that a special exhibition has had a non-living exhibit as its most popular element. This information contributes to the understanding that non-biological exhibits may be the most popular exhibits. In the same study, it was found that the inclusion of objects, such as fishing rods or snorkel masks, in text exhibits more than doubled the average percentage of visitors attending such exhibits.'

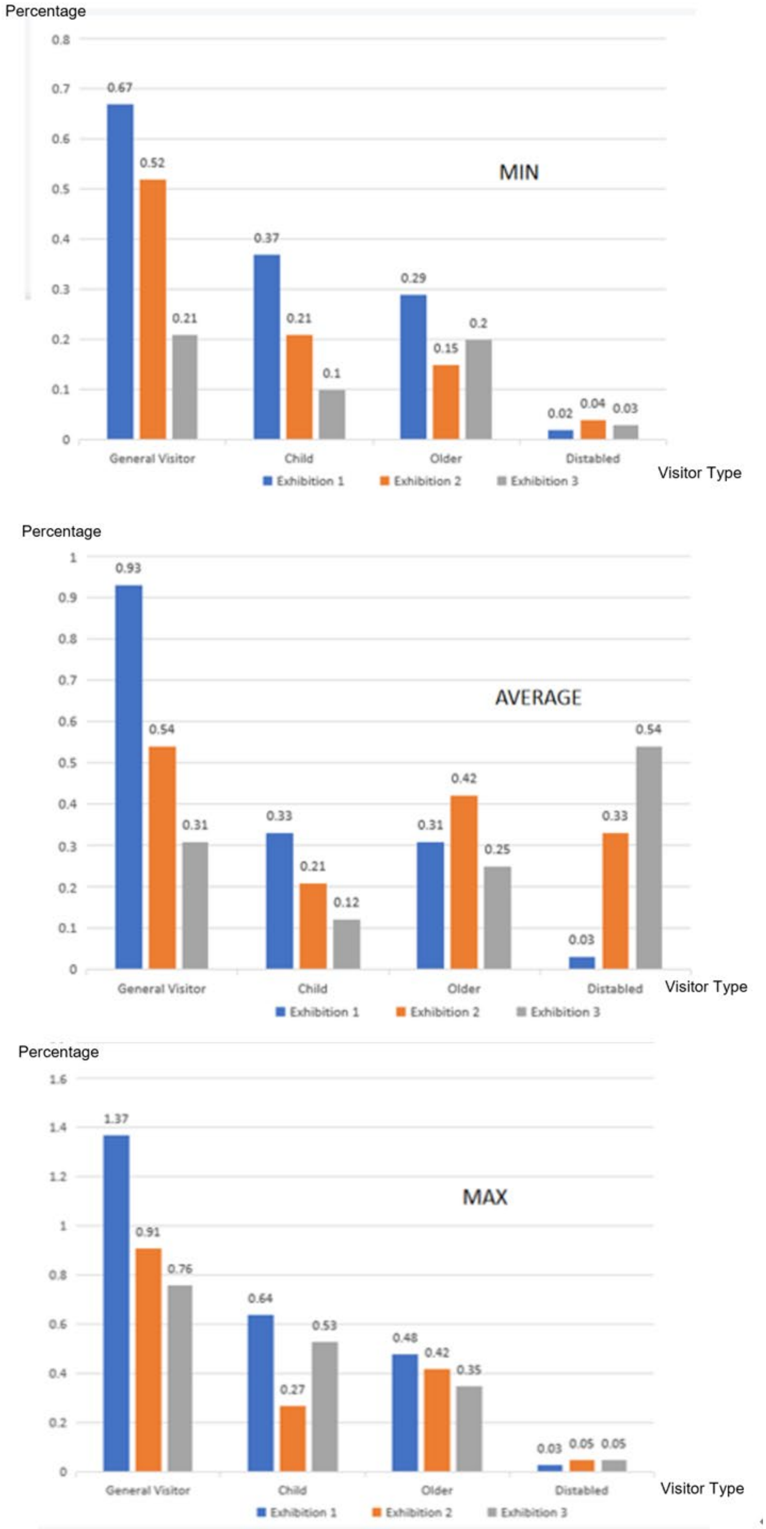


Figure 6-3: Percentage of visitors' memories of all objects in the exhibition

Table 6-6: Percentage of visitors' memories of each item in the exhibition

MIN			Percentage of Visitor Memory Values for Different Types of Artwork		
			A. Painting	B.Interact Item	C.Non-interact Item
Random Value	Simulation exhibition1	General	0.32	0.41	0.07
		Child	0.18	0.25	0
		Older	0.6	0.65	0.15
		Distabled	0	0.13	0
	Simulation exhibition2	General	0.1	0.26	0
		Child	0	0.19	0
		Older	0.47	0.05	0
		Distabled	0	0.23	0
	Simulation exhibition3	General	0.06	0.27	0
		Child	0	0.16	0
		Older	0.5	0.78	0
		Distabled	0	0.13	0

AVERAGE			Percentage of Visitor Memory Values for Different Types of Artwork		
			A. Painting	B.Interact Item	C.Non-interact Item
Random Value Data	Simulation exhibition1	General	0.422	0.445	0.138
		Child	0.177	0.263	0.213
		Older	0.51	0.552	0.154
		Distabled	0.038	0.151	0.002
	Simulation exhibition2	General	0.084	0.298	0.213
		Child	0.010	0.181	0.182
		Older	0.525	0.598	0.064
		Distabled	0.087	0.137	0.027
	Simulation exhibition3	General	0.086	0.313	0
		Child	0	0.215	0.264
		Older	0.494	0.648	0.072
		Distabled	0.043	0.138	0

MAX			Percentage of Visitor Memory Values for Different Types of Artwork		
			A. Painting	B.Interact Item	C.Non-interact Item
Random Value	Simulation exhibition1	General	0.57	0.51	0.29
		Child	0.23	0.65	0.03
		Older	0.84	0.84	0.2
		Distabled	0	0.43	0
	Simulation exhibition2	General	0.1	0.36	0.15
		Child	0.08	0.16	0.05
		Older	0.36	0.56	0.2
		Distabled	0	0.23	0
	Simulation exhibition1	General	0.07	0.38	0
		Child	0	0.74	0
		Older	0.41	0.55	0.09
		Distabled	0	0.16	0

6.6.3 Simulation Data with Sigmoid Function

After re-adding the Sigmoid function, we re-updated the comparison of the simulated data. Comparisons were made from Figure 6-4 to Figure 6-9. We can see the number of memories for each artefact in the simulated data for visitors without the sigmoid function added and for visitors with the sigmoid function added. In the graphs, NormalrealiseA represents the number of artefacts visitors remembered for paintings, NormalrealiseB represents the number of interactive artefacts remembered by visitors in general, NormalrealiseC represents the number of non-interactive artefacts remembered by visitors, and so on. It is clear that when interactions between agents are added, the number of artefacts remembered by visitors for various artefacts shows a clear downward trend, meaning that as more and more visitors interact or view the same artefact at the same time, their memory of the item decreases.

Figure 6-4: Model 1 - Data with sigmoid function

Model 1, Data With Sigmoid Function

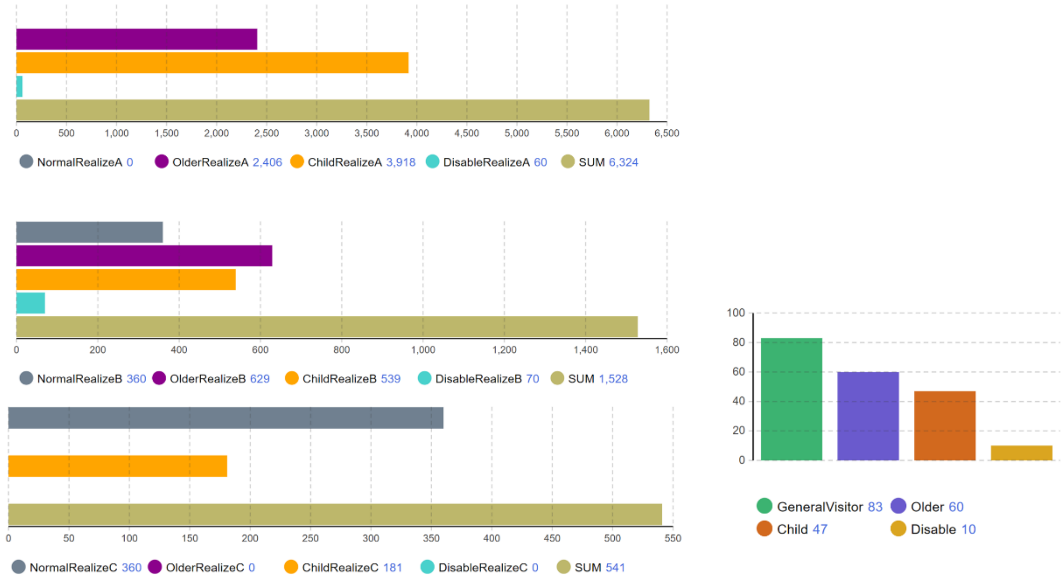


Figure 6-5: Model 1 - Data without sigmoid function

Model 2, Data Without Sigmoid Function

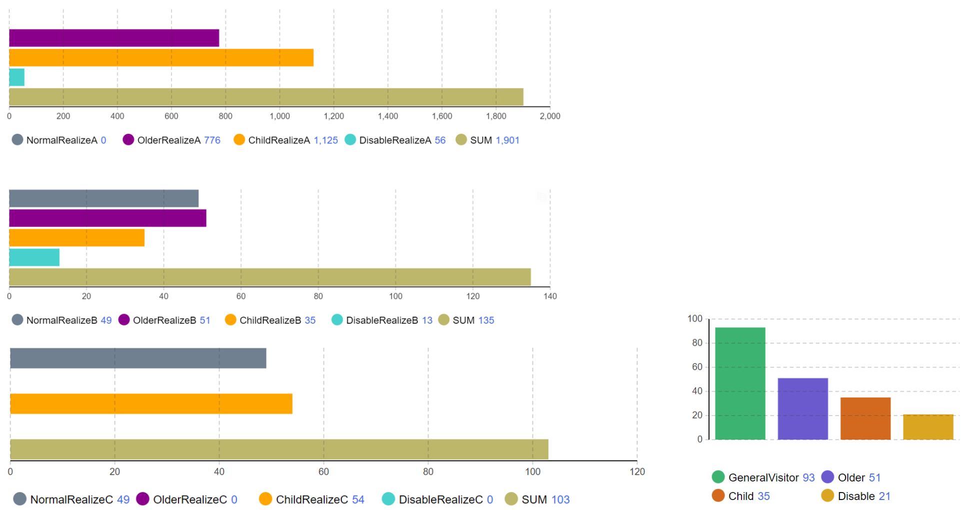


Figure 6-6: Model 2 - Data without sigmoid function

Model 2, Data With Sigmoid Function

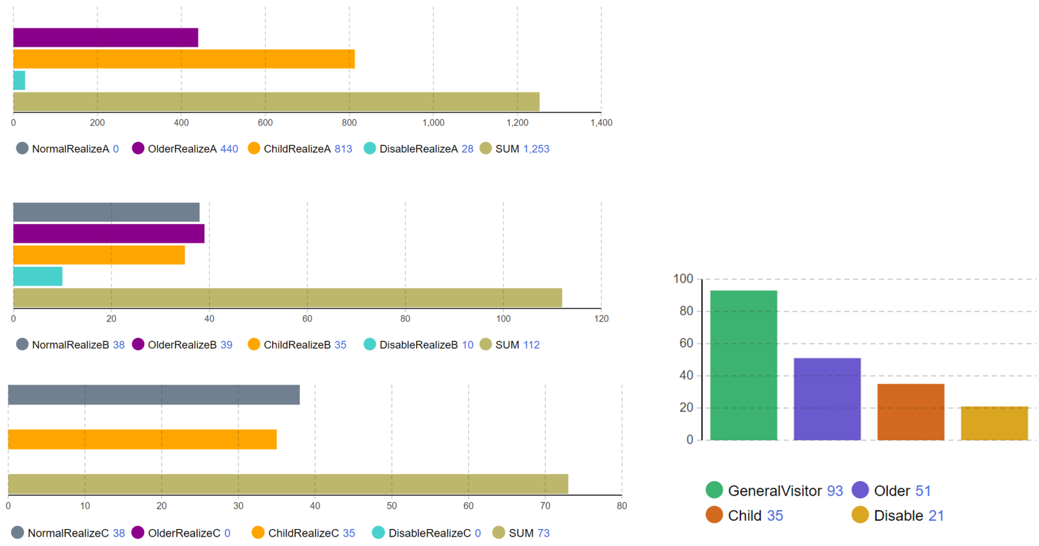


Figure 6-7: Model 2 - Data with sigmoid function

Model 3 Data Without Sigmoid Function

Figure 6-8: Model 3 - Data without sigmoid function

Figure 6-9: Model 3 - Data with sigmoid function

6.6.4 Data Results and Validation

To demonstrate whether our model could be realised with actual data, we continued our memory experiments in the on-site MK Gallery. First, the preparation material was 60 images from the exhibition. Then, after visitors had seen the entire exhibition, we asked them to recall their memories of these 60 images. The calculated values were then brought into the exhibition 3 and simulated under the same time and number of people conditions. At the end of the simulation, the results are computed and presented in Table 6-7. The general visitor group had the highest memory recall percentage value of all types of visitors, the same as the case of deterministic data we averaged in the previous simulation across the three exhibitions. The next type of elderly group had the higher memory recall of all types of visitors, which was the same ranking as the data from simulated Exhibitions 2 and 3, although slightly different from simulated exhibition 1. Finally, the children's group was the weaker of all the simulations in terms of memory recall, except for exhibition 1.

When entering the parameter values, we likewise gave the range of values for the actual data. Therefore, 100 simulations of the data were carried out, and the intermediate values were taken out for analysis (Table 6-8). It can be seen that the percentage of interactive exhibit types is relatively high in each type group of visitors, indicating that the recall of interactive artwork by visitors after viewing the exhibition is very high, which is consistent with the simulations we assumed earlier. There is the type of painting of the artwork. It is clear from the values that although there is a certain percentage of paintings if the participants are in the children's group, they have little sensitivity to memory recall of the type of painting. Finally, only the older group had some memory recall of artworks that could not be linked, confirming that those in the older group may have studied, researched or remembered in greater detail during the visit. In terms of the results, putting actual data into our model reflects results that show our model is working correctly. To check if the data is correct, for example, 10 visitors are entering the system, and we know their MVR by setting the parameter for each visitor agent. By knowing the MVC of each type of artwork through the setting of the parameter of each artwork agent, we can accurately calculate the amount of memory that the visitor can remember, i.e., when the visitor's MVC is greater than the MVR of the artwork, the visitor can be able to remember one object and the total number of memories will increase.

From a design point of view, although we brought real data into the model, we created and verified that the real situation was consistent with what we simulated. There are indeed different types of exhibitions, such as photography, painting, installation, interactive media stations etc. Many exhibition teams plan their exhibitions so that ‘first visitors will do this, then they will do this’. They assume that visitors will use the exhibition elements in the expected order and spend whatever time is necessary to build an understanding of the exhibition information. However, whether from memory data, tracking or temporal data, it is clear that visitors go where they want to go. They will skip some elements and visit only a third of them, spending much less time than is usually assumed. These trends in visitor behaviour have clear implications for museum practitioners designing educational exhibitions who are concerned with effectively communicating their pedagogical objectives: if the main message of an exhibition requires extensive label reading, most visitors may not understand it. If the main message requires a visit to a high proportion of elements to piece together the story, most visitors may not understand it. If an exhibition contains different themed sections, visitors will need to use many exhibition elements in each section to understand the different themes. The different types of visitors in the model show that visitor behaviour is not random and that patterns can be drawn out. Visitors who spend relatively more time will typically stay on more elements and engage with more of what the exhibition offers. Rather than spending more time at a few stops, this pattern appears to be one of spending more time by making more stops. For many exhibitions, it is typical for the average total visit time to be less than 20 minutes in a house. The visitor's experience is made up not of what the exhibition offers but what they choose to attend. In order to capture the visitor's attention, we first need to engage them. By carefully observing the way visitors behave, we can learn appropriate ways of informing the exhibition design to increase visitor satisfaction.

Table 6-7: Practical data results of the ABM in exhibition 3 layout

Simulation exhibition3		Tourist memory percentage			
	NO.	General	Child	Older	distabled
Real data in Model 3	MIN	1.12	0.08	0.3	0.01
	Average	1.44	0.06	0.48	0
	MAX	1.8	0.04	0.52	0

Table 6-8: Percentage of visitors' memories of each item in the exhibition 3 (Real data from memory experiment)

MIN	A. painting	B.Interact	C.non-interact
General Visitor	0.64	57.00	0
Child	0.00	9.00	0.00
Older	0.17	14.00	5.00
Disabled	0	0.00	0.00

Average	A. painting	B.Interact	C.non-interact
General Visitor	0.81	75.00	0
Child	0.00	7.00	0.00
Older	0.21	23.00	8.00
Disabled	0	0.00	0.00

MAX	A. painting	B.Interact	C.non-interact
General Visitor	0.99	95.00	0
Child	0.00	5.00	0.00
Older	0.23	26.00	8.00
Disabled	0	0.00	0.00

The interaction of Agent in ABM is also one of the important links. To solve the problem of agents interacting with each other, we set the time/memory recall spent in each artifact as a function of the number of visitors (i.e., the more visitors competing for the same artifact, the less memory recall) that is reserved for the artifact. The sigmoid function can be expressed as shown in the Figure 6-10. X axis represents the number of cultural relics remembered by tourists, and Y axis represents Attention parameter (memory value of artifacts). In other words, when a cultural relic is watched by the audience, the fewer the number of people watching at the same time, the more times the cultural relic will be remembered. Then the memory value of this artefact will become smaller and easier to remember, and vice versa. For details, please refer to Table 6-2 Model Logic, 2.5, 2.5.3 Interaction.

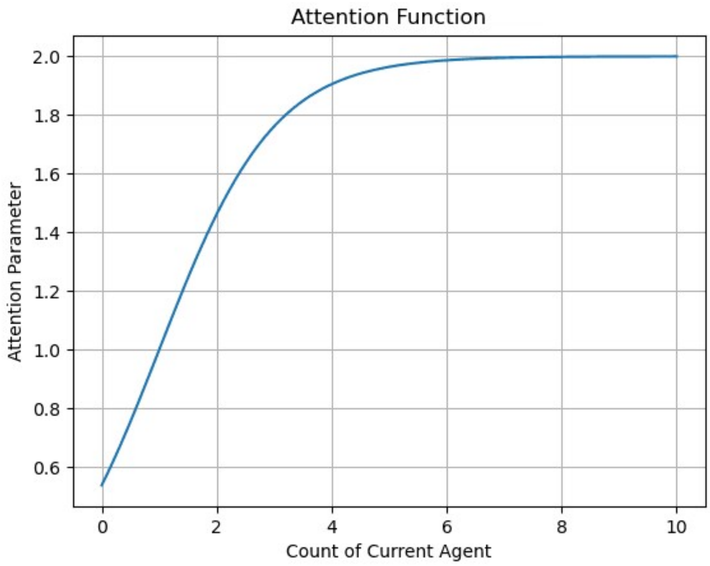


Figure 6-10 Sigmoid function diagram

6.7 Conclusion and Future Work

In summary, the ABM approach can help museum planers identify issues to improve their layout design at the early design stages. The improved designs can help visitors enhance their interaction experience better and their memory latency. This allows more exhibition to be learned and retained. In the simulation, we studied impact of museum layout design on visitor memory retention, i.e. interaction between visitors and artworks. Visitors are classified into four groups: general, elderly, children, and disabled, while artworks are classified into three categories: interactive exhibits, paintings and non-interactive objects. The experimental results show that the memory index for interactive exhibits is susceptible to memory recall of interactive artworks, followed by paintings, regardless of the types of visitors.

The ABM approach can break the traditional way of learning research and reduce unnecessary time loss. However, this causal relationship may also be less applicable when extending the scope of the problem to a more general context. At the beginning of the study, we wanted to measure visitors' short-term and long-term memories of different objects in the form of ABM simulations, but we found that the span of memory events could not be modelled in the way that computer software was designed. While it is possible to create software agents to construct ABMs that show levels of human intelligence and consciousness, human societies are indeed a product of human intelligence and consciousness, and some of the characteristics of essentially human traits are very flexible and subject to some uncertainty in models of human societies. The AMB approach is designed to provide designers and curators with a novel, convenient and time-saving perspective on the way visitors behave. This approach allows for a rich set of characters or combinations of visitor behaviour in the simulation or even a general categorisation and measurement of the emotional value of the artwork itself. However, it may be necessary to dig deeper or interview visitors about their real and personal feelings.

7. DISSCUSSION

Based on the research findings of the whole thesis, this chapter provides detailed answers to the questions and hypotheses in Chapter 1. It discusses the possible effects on human memory of multi-sensory experiences. In addition, the limitations of this thesis and their possible solutions are given at the end of this chapter.

Many different approaches to the study of memory exist, in multiple disciplines. Museologists have studied the role of museums as repositories of memory, or how memories of museum visits are related to identity and motivation. Psychologists have created practical methods to examine the quantity and quality of information encoded and recovered, while archaeologists have explored the use of memory to manage memory storage experiences. Few studies have attempted to draw on these fields to understand how various displays and sensory experiences contribute to the creation of personal memories (Sweetman, Hadfield & O'Connor, 2020).

In order to fill this gap between the disciplines, this study draws inspiration from three directions: the importance of the museum space, artefact attributes, and working memory retention. Through these, we address the gap in current knowledge:

> *Can different sensory experiences within a museum's content enhance visitors' knowledge transfer or memory retention?*

Based on the research gap, this thesis aims to investigate the relationship between artefacts, space, and human working memory in museums. To understand how visitors interact with spaces and with different kinds of exhibits, we need to study their sensory behaviour and memory retention. We explored whether memory relationships can lead to knowledge translation for users. We also captured visitor behaviour through an agent-based model (ABM) in order to simulate visitor behaviour and provide feasible solutions for the design of museum layouts, interactive experiences, etc. The model is intended to improve experiences of human interaction with exhibits and thus inspire new curatorial approaches.

7.1 Research Question, Hypotheses and Practical Implementations

In this section, we will answer and discuss the study’s three main questions and its three respective hypotheses.

Question 1: How can human multisensory experiences be assessed or captured?
Hypothesis 1: Museum memory —— More interactive sensory experiences will increase the transfer and retention of knowledge.

The literature review forms the basis for our first question. Through observations and group surveys we investigate how visitors interact in museums. We have found relatively complex visitor behaviour in museums and exhibitions. Visitors are concerned not only with the exhibition’s narrative content but also with the ways in which they can interact with it. Each type of visitor behaves differently and is concerned with different aspects.

Exploring Hypothesis 1 through group research, we determined that as people’s experience of sensory interaction increases, their memory storage capacity can indeed become richer and memory loss can be delayed.

Key findings:

We found that when visiting a museum or an exhibition, visitors usually enjoy the level of knowledge and interest that an exhibition brings from four different perspectives:

1. Artefact: In the process of viewing an exhibition, the visitor's attention is usually focused on the objects on display. In the case of the things themselves, visitors are more interested in the innovative ideas, future trends, quality attraction and the value behind it in different types of exhibitions.

2. Experience: Visitors prefer to experience the full spectrum of the exhibition, and favour a unique experience. Appealing features include novel ways of communicating. It matters to visitors whether the narrative line of the display is

impressive, whether there is interaction or communication, and whether information is clearly disseminated.

3. Space: A few visitors are space-sensitive, as are designers. Such visitors will have different concerns about the area within which the exhibition is set: for example, spatial planning, functions or tour routes.

4. Knowledge transfer: Knowledge acquisition is of particular interest to visitors, most of whom want to gain new knowledge or inspiration during an exhibition. Most visitors also give thought to the exhibition's educational value.

Through our final group investigation, we have also summarised the three ways in which visitors view the exhibition:

Self-thinking: After reading through professionally written descriptive text, individuals combine their perceptions and other experiences of the physical object. They form questions and continue their observation in light of these.

Communication: Visitors prefer direct communication through spoken language. This general approach, however, may not impress them.

Observation: Visitors prefer to explore and solve problems while observing objects.

Discussion:

The study shows that more interactive sensory experiences increase visitors' knowledge absorption and retention. However, further research is yet to be conducted on the duration for which knowledge is retained in memory.

In the first stage of the study (Chapter 3), the feedback from the interview allowed us to draw up a series of themes for analysis: personal preferences, impressions of the exhibition, participant evaluations, categorisation of participant behaviour, and interactive effects. We interviewed the majority of respondents who indicated that they preferred art, design and history museums or exhibitions. However, some were not used to visiting them, and some did not visit them at all. At a personal level, interests, attitudes and other personal motivations encourage a person to visit a museum and be curious about its contents. Where social groups are concerned, the results show that most participants prefer to visit exhibitions with friends and family. This exhibition space was able to bring people closer together, and information can be better shared and discussed within it. Those who enjoyed visiting the exhibition could also gain a richer sense of having had personal experiences than the knowledge brought to them by the objects themselves.

Some participants felt that they had learnt about other areas and had gained new inspiration and knowledge during the exhibition. Following in-depth interaction with the artefacts or exchanges with the designers, the warehouse workers better understood the objects they were interested in. Even during the conversation with the designer, participants unexpectedly gained new knowledge. Acquiring different perspectives and opinions from the discussion enhances the viewing experience. During follow-up interviews many days later, it was clear that some of the participants could still recall in detail the particular information content of the exhibits they had experienced in person. Of course, there were also some very negative comments from any visitors who found the exhibition content uninteresting.

Analysis of the participants' comments suggests that the design of museum exhibitions must be considered from several perspectives. From that of social interaction, close communication between visitors, designers and producers helps the interviewees to observe and understand the effects. From a spatial design perspective, some people were confused by the layout of the space and explained that the confusing layout of the room prevented them from concentrating or thinking. As some researchers have argued, traditional approaches to designing exhibition spaces do not meet the public's needs. User experience and interaction should be considered a core competency in design (Wang & Xia, 2019). Exhibition design should meet not only visitors' visual requirements but also the requirements of designers, the visitors and other stakeholders. Design elements form the core of the customer experience, and visitors' feelings and reactions come from these design elements. Different forms of interaction, such as spatial design or other environmental factors, can give visitors a better experience and deepen their impression of the content (Falk & Dierking, 2013; Forrest, 2014).

Question 2: Is there a link between the visitor's sensory experience of interaction and the various types of exhibits in the museum?
Hypothesis 2: That the experience of sensory interaction has a long-term impact on increasing visitors' short- and long-term memory.

To answer Question 2, we focused more on the experience of interaction between the participants' memories and the exhibits. Due to the closure of galleries during the COVID-19 pandemic, it was not possible to bring large crowds together, so we mainly used an online experiment. As we had visited the Bank of England Museum in the UK during our previous field study, and this museum contains a lot of knowledge about British banknotes and coins, when designing the experiment, we thought we could study participants' memory of observing coins through physical observation of a £1 coin.

Key findings:

1. Multi-sensory interaction evokes more memories of objects from short-term memory than visual interaction alone.

2. Participants recall non-verbal memories of artefacts' attributes, such as shapes or colours, more accurately.

3. Image memory is more stimulating than text memory.

4. Participants' long-term memory gradually faded, but the shape or pattern of the object could be accurately judged. Some participants could narrate the general story for the next part but lacked keywords or numbers.

Discussion:

This study not only focuses on the objective measurement of people's understanding of everyday objects but also further analyses the duration for which knowledge is retained in memory, as in the first hypothesis. The final results of the study indicate that in short-term memory, multi-sensory interactions evoke more memories of objects than vision alone. However, where long-term memory is concerned, a visual stimulus such as a colour or shape left a lasting impression on the participants. Memories of more detailed written descriptions faded over time.

The study has focused throughout on memory experiments for museum exhibition spaces, incorporating visitors' sensory interactions. The experiment with a pound coin is intended to be equivalent to a visitor's interaction with an artwork in an exhibition. Some of the artworks in the current exhibition fail to impress the visitor because there is no physical contact with them. Another interesting phenomenon is that it is often assumed that taking a photograph of an artwork helps to deepen one's memory of it. However, in most of the studies, the subjects could not remember the specific content of the pictures shortly after viewing them. Visitors did not think of information about a particular exhibit immediately after visiting all the items, only about the most interactive and impressive displays during the visit.

Most participants in the study made apparent errors and omissions in their understanding of the coins. It was also evident from some participants' performances in the pictures that the coin section did not feature prominently. As Lawson (2006) indicated, most people had a cursory conceptual understanding of familiar everyday objects, even when the information was frequently encountered and easily understood. There was little or no evidence of knowledge of causality, which is inconsistent with a robust version of explanation-based classification theory. Moreover, participants' memory of more detailed textual descriptions faded over time. In Experiment 3, we changed the stimulus conditions to video, audio and physical objects. All other conditions being equal, participants' recall was immediate. When comparing the short-term memory data from Experiments 2 and 3, it was evident that the audio–visual–tactile recall in Experiment 3 was more accurate regarding the correct answer to each question. Two weeks later, we conducted a second memory recall test for participants who had received audio–visual–tactile stimuli in Experiment 3. We found an interesting phenomenon. The data showed higher accuracy in memory recall after two weeks than in picture-word recall in Experiment 2, especially when the questions involved colours, shapes, etc. The accuracy of memory recall was very high. The meaning of pictures is closely related to their content, but people did not remember all the details of the pictures because they have no real purpose. A coin is a meaningful object, and the specific details that appear on the coin, and the interrelationships or spatial relationships between these details, are also significant (Nickerson & Adams, 1979). It has been found that people's perceptual memory of everyday objects such as coins and road signs is surprisingly good (Nickerson & Adams, 1979; Martin & Jones, 1998). However, people do not remember specific numbers or words very clearly, due to the fact that image memory is more stimulating than textual memory.

Question 3: Can this method of interactive sensory experiences and memory experiments be applied to real case studies?

Hypothesis 3：As technology evolves, traditional learning methods for observing visitor behaviour in museums and their exhibits can be challenged by computer simulations.

Key findings:

<u>Memory impact</u>

1. Interaction is most critical for visitors' memory because an increase in interaction can make visitors feel more involved.
2. Interactive artefacts provide different experiences for different types of tourists.
3. Children can remember more about the objects they interacted with.
4. Any item that has been studied for a long time can yield deep memories for the elderly.
5. Interactive activities and iconic products are most helpful to young people's and general tourists' memories.
6. Students will pay more attention to target items.

Spatial layout impact

1. The previous analysis can yield some suggestions about exhibition arrangement for the curatorial team. For example:

2. Comparing the current heat map of the plan1&2&3, the artefacts in Exhibition 2 are placed to suit activity, but the route planning is too complicated for a one-way system.

3. Curators should increase the obvious memory points and eliminate tourists' fatigue.

4. When a large number of exhibits have no particular classification, they can be arranged at the entrance or exit. Items at entrances and doors are more likely to make an impression on visitors' memories than objects that are easily overlooked.

Discussion:

We have previously cross-referenced elements of cognitive memory and design. However, having combined the two, we have also been pursuing an alternative approach that challenges the traditional way of experimenting on memory by attempting to make observations about human behaviour using computer simulations.

ABMs offer many opportunities as a solid, adaptable technique for solving some of society's most persistent problems, particularly multidisciplinary ones. According to Epstein (1999), ABMs allow us to 'transcend some artificial limitations that may limit our knowledge'. Although the study of visitor behaviour has long been a popular topic among museum professionals, most learning methods still rely on traditional approaches such as interviews, group studies and questionnaires. However, ABM research in computer science adds a fresh and unique perspective to the study of museum visitor behaviour. Recent research has focused on how visitors view exhibits in museums according to the structure of the display space. The pedestrian freedom offered by ABMs allows for the testing of complex interactive behaviours in museum environments. The dynamic paths visitors take through the various exhibition rooms can be visualised. Visitors' reactions to each artwork can be quantified, as well as their memory index and the level of pleasure they take in the work. The time the user spends on a painting and the visitor's personal memory experience may be influenced by the same interaction. Our research at MK Gallery in the UK shows three different exhibition simulations. The study produced a series of observations of visitors' recall experiences and the level of participation in the exhibition. The ABM is applied at the conceptual stage of design, but before all design choices are completed. Using the model at this juncture will help designers identify difficulties in the early design stages and change the design based on the model's findings (Çağdaş, 2009), assisting visitors in enhancing their interactive experience and increasing their memory latency, and allowing more of the exhibition content to be learned and retained. When we compared the data from the computer simulations with those from the traditional experimental approach, the results were essentially similar.

This study indicates that we can expect simulations to help design improved iterations and produce the results we want by avoiding fixed patterns. This could replace the traditional methods of learning research and reduce unnecessary loss of time.

7.2 Research Limitations and Possible Solutions

The limitations of this thesis and their possible solutions mainly include the following:

Although the research in this thesis reveals important findings, there are limitations. There were four uncertain aspects of the memory tests because all tests were administered at specific times via the Internet. Firstly, it was uncertain whether the participants had carefully prepared the requested daily items for observation. Secondly, it was impossible to determine accurately whether the participants had completed the 30-second timing session of the experiment's interference phase. Thirdly, at the beginning of the experiment, we wanted participants to draw an impression of the coin as a painting, as research has shown that drawing improves memory in everyday life and education (Wammes, Jonker & Fernandes, 2019). However, this step was not done well online due to the conditions that prevented us from getting extensive feedback about the drawings via the Internet. Finally, the experiments were divided into short-term memory (image–text), short-term memory (video–audio–text–object) and long-term memory (video–audio–text–object). In the comparison process, the data for long-term memory (image–text) might have been complete if they had also been recorded in Experiment 2. In order to make the experimental data more comprehensive and manageable, sketches could still be used for experiments in future studies, giving a more visual indication of how much the audience knows about everyday objects. Cross-cognitive disciplinary knowledge is added to museum learning to improve audiences' experience and learning. In the future, deeper research into working memory will lead to a more in-depth study of the audience's memory of sensory interactions. Future simulations can further explore visitors' interaction with the exhibition space and exhibits, especially to research the differences between different kinds of exhibits.

This thesis focuses on the theoretical design and performance analysis of ABMs in measuring visitor memory behaviour. Still, the intelligence and data from these designs and their models have not reached fully mainstream application in museums. Even though we have tested them further and obtained good results, we can only show that we can use ABMs in this way to help designers make changes at the pre-design stage. Therefore, more sophisticated techniques and further development are required to investigate the use of these models or methods and whether they can be better applied to visitors' cognitive behaviour and spatial relationships.

ABM simulation methods in computer science can provide designers with a novel approach to understanding causal relationships, but one that may become less applicable when extended to more general situations. At the outset of the study, we wanted to measure visitors' short- and long-term memories of different objects in the form of ABM simulations, but we found that the span of recalled events could not be modelled in the way the software was designed to support.

This study modelled visitors' social behaviour as a simple choice, using overall visibility as the only parameter. However, this is unrealistic, as many factors may influence visitors' minds when viewing artwork. Factors such as visitor preferences and people's level of art appreciation can be used as a way to create more complex visitor decisions. Multi-criteria decision-making (MCDM) analysis can be combined into this model for a more realistic approach. The study also models visitors as a unit, meaning that each visitor enters the museum individually. If more complex visitor–visitor relationships (e.g. group movement, companionship) could be added to it, the model would be more realistic, taking into account additional factors in each visitor's decisions. In this study, the agent-based model used a set of bounded ranges of values; other studies have used a fixed value rather than a range. In future work, we hope others may try to implement the model under a broader range of constraint values to explore more similarities and differences in each use case. Other methods of validation could be explored to test the generated models further. While software agents can be used to construct agent models of part of human society. However, human society is a product of human intelligence and consciousness, and the flexibility and probabilistic nature of its features cannot, to some extent, be fully replaced by software agents.

Due to our geographical location and the COVID-19 pandemic, we were unable to conduct multiple in-depth interviews and to make more observations of visitors to the museum; this affects visitors' feedback and their comments on their behaviour to some extent. Since no one has previously attempted to use computer simulations to observe visitors' memory behaviour, the technical limitations lead to some deviation of the study results from the situation modelled. Therefore, more understanding of ABMs and software is needed for future research.

8. CONCLUSIONS AND FUTURE WORK

8.1 Conclusions

In this thesis, we use four objectives to achieve our research goal of understanding how artefacts, spaces and visitors' working memories in museums can be physically interconnected. This relationship is then represented in a simulated form through the ABM approach, and a new research technique is explored to help curators and designers predict exhibition spaces' functioning and visitors' behaviour in a cost-effective way. This thesis also responds to the three questions we asked at the very beginning of the study.

The specific conclusions concerning the original objectives are as follows:

Through Objective 1 (Chapters 2 & 3), a systematic literature review, and actual observations of 12 museums across London, we identified research gaps and research directions concerning museum space, artefact properties and visitors' working memory. We have established that visitors' memories are retained because of the interactive sensory experience of museum exhibitions. In contrast to previous research on the design of exhibition spaces, we sought to examine visitors' own experience of interacting with the space and exhibits, and how the spatial arrangement influenced this experience, while observing and interviewing visitors in a variety of ways. Through a behavioural analysis of the findings, the research themes were refined into the visitors' post-exhibition memory experiences. Our approach was accurately responded to in the final pilot study. We found that the content of visitors' reflections within the exhibition would focus on the artwork, educational significance, spatial design and knowledge transfer; visitors would not only respond to the exhibition they were viewing, but would also expect the content or experience it provided to inform them about their own experiences or needs.

Based on the study of Objective 1, we gained an intuitive understanding of visitor behaviour in museums, namely that visitors' memory is directly related to sensory interaction. We eventually turned our attention to the two points of visitor memory behaviour and sensory interaction. We conducted an extensive literature review of working memory, memory theory and experimental methods based on Baddeley and Hitch's 1974 theory of working memory, and summarised 50 experimental methods suitable for short-term and long-term memory experiments (Chapter 4). The experimental methods were redesigned to suit the prevailing situation and to include a session on interaction. In contrast, the objects we utilised for observation, although ordinary £1 coins, were the same as those displayed in the Bank of England Museum.

In Chapter 5, a questionnaire was used to gain an initial understanding of visitor behaviour in the exhibition space (Chapter 3), guiding participants to answer several questions about the environment, object interaction and memory after visiting the exhibition. Initial feedback was obtained about visitors' real memories of everyday objects. The questionnaire was sent to over 1,000 people and 581 responses were received. Of these, Experiment 1 and Experiment 2 involved 204 submissions, Experiment 3 involved 2.12 participants and Experiment 3 involved 165 people. In the feedback, the results showed that multisensory interaction was more likely to evoke short-term memory for objects than vision alone. Participants recalled non-verbal memories of artefacts, such as shapes or colours, more accurately. Interestingly, image memory was more stimulating than word memory. Participants' long-term memory faded, but most could accurately identify the shape or pattern of the object, and another proportion of participants could name individual features or simple statements, but lacked key words or numbers.

Through previous experimental analysis, we were able to grasp the memory patterns of the users. In the end, because of the environment of Covid-19, we used the ABM computer simulation method to simulate the real gallery space and visitors. The purpose of using ABM was firstly because this method can be low-cost and time-saving. Secondly, it allows for an innovative approach to traditional museum research.

In our simulations we found that ABM can help museum planners identify, in the early design stages, problems that can then be predicted and their layout designs can then be improved. The improved design can help visitors to better enhance their interactive experience and their memory of the content. In the simulations we investigated the impact of museum layout design on visitors' memory retention, i.e., the interaction between visitors and artworks. The experimental results show that the memory index for interactive exhibits is susceptible to memory recall of interactive artworks, followed by paintings, regardless of the types of visitors.

To confirm that our simulations were correct, we also eventually conducted a small-scale traditional memory experiment with visitors in the gallery. In the end it was confirmed that the results of our simulations matched the realistic memory experiments. The ABM approach allows for a break with the traditional museum visitor observation approach to research that not only defines human behaviour, but also allows for observations of human memory. However, some limitations do exist. For example, ABM does not function as a complete substitute for human emotion, cognition and activity when the scope of the problem is extended to a broader context, aspects that may require more background investigation of the visitor. As another example, for memory research, the ABM simulation format cannot accurately measure the time-crazed span of memory. Although the agent can construct hypotheses about human behaviour, there is individual uncertainty about tourists' perceptions and experiences, and the ABM agent can only make some predictions for large groups of people, while more background research is needed for specific situations.

8.2 Contributions to Knowledge

The contribution of this thesis can be described in two ways:

<u>Public contributions</u>

We created three agent-based model simulations, based on actual exhibitions at MK Gallery. We have demonstrated that our computer simulations can be performed in real spaces by comparing the simulation data with real visitors' data.

<u>Academic contributions</u>

1. We determined that people's impressions of everyday objects in memory are not what they think they are. Moreover, we used the same objects on display at

the Bank of England Museum, i.e., the things that visitors would realistically anticipate in the gallery, for the experiments we conducted.

2. In the memory experiment, we confirmed that multi-sensory interactions have more memory retention than traditional exhibition methods, i.e., sensory interactions with visual and textual stimuli. Recognition and recall are more substantial when objects are processed, suggesting that multi-sensory experiences can enhance memory of the objects and their associated ‘stories’.

3. Research has shown that information such as the shape or colour of an object is more convincing than descriptive labelling information, such as a name or date, while depiction of a person’s colour more likely to be recalled than other information. This result provides the basis for the computer simulations we will need to carry out later.

4. The literature review found no articles about similar work using ABMs to simulate visitor memory in the exhibition space.

5. The ABM simulation brings methodological innovations to the curatorial or design team. For example, the placement of exhibits, their routing and visitor behaviour can all be simulated and predicted at no cost before the exhibition begins.

8.3 Future Work

Multiple disciplines have produced excellent results in their own investigations of memory. Psychologists have developed experimental methods to assess the quantity and quality of encoded and retrieved information; museologists have focused on the role of museums as memory repositories, or examined memories of museum visits in relation to identity and motivation; and computer scientists are studying various simulations of human behaviour, including events, escapes, and fire prevention classes. To date, few studies have attempted to draw evidence from these fields together to understand how different types of exhibits and sensory experiences contribute to forming individual memories. Our findings combine knowledge from museology, design, memory research and computer science. The result is a computer simulation that uses memory research and learning methods to present observations on visitor behaviour and the design of museum spaces.

A well-designed museum should transport visitors across time and space, and be filled with intriguing exhibits and rich sensory experiences to enhance memory encoding and retrieval. Objects and artefacts depicting humans and animals have been found to be well recalled. In this and previous research (e.g. Massaro et al., 2012), careful descriptive writing was chosen to promote interest and facilitate more profound knowledge. As we discovered in our experiments, the practical experience of material culture can act as a catalyst for conversation, discussion, and listening, with benefits for museums' general social function as well as for more specific educational purposes, such as developing a material culture for literacy programmes based on the surrounding environment.

In the future, design and curatorial staff could learn more from the computer staff, ask them to improve computer simulations and introduce them into the design process. Such simulations would then allow designers to pre-judge the whole design before incorporating an offline assessment of visitors, and to gain a preliminary understanding of visitor behaviour in order to control the flow of visitors through museum spaces. Research on the value of sensory experiences in museums is currently being conducted by many researchers across many possible boundaries. As a provision for understanding how best to relate visitors to the actual museum environment, future work in memory research will hopefully involve using different experiments in museums to assess the value of various sensory engagements for different types of visitors, with a particular focus on children or people with disabilities. Several museums and galleries in the UK have undertaken excellent pilot projects in this area and have produced valuable guidance on programming for people with dementia and their careers, such as the Tunbridge Wells Museum and Art Gallery Dementia Toolkit.

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APPENDICES

Appendix A The Content of Questionnaire in Chapter 3

Part 1: Questions about exhibition experiences

Q1: Do you often visit exhibition or museum?

Yes.   Sometimes.   No.

Q2: Who do you visit the museum with (Multiple options)

Alone.   A partner/ friend.   Your family.   Your school/college.   A tour-group.   Other(s).

Q3: What type of exhibition/museum is most attractive to you?

Art/design. Historical. Science.   Geology.   Other (s).

Q4: Thinking about the last exhibition you attended; How did you feel about it?

Extremely good. Moderately good. Slightly good. Neither good nor bad. Slightly bad. Moderately bad. Extremely bad.

Q5: Do you remember the contents of this exhibition?

Definitely yes

Probably yes

Might or might not

Probably not

Definitely not.

Q6: How long has it been since the last time you visited an exhibition/museum?

______.

Q7: In the recent exhibition that you visited, to what extent did the content interest you?

Not at all 1 2 3 4 5 6 7 8 9 10Extremely

Q8: What makes an object interesting to you?

The way it looks (eg. Colour, shape, size, etc.).

Personal interest in that type of object

Having seen it before

It looks very curious and wanting to know what it is

Others________.

Q9: What aspects are you more important when you visit an exhibition/museum?

Arrangement of objects

Arrangement of space

The quality of objects on display

Length of information content available

Ability to interact with objects

Interact with knowledgeable staff

Environment (e.g. light, space design, etc.)

Others________.

Q10: Which style of guide method will you prefer / which was the most successful way to stimulate your interest in the exhibit? (Multiple options)

Booklet/ Touching the exhibit/ Audio equipment/ Smelling the exhibit if necessary/ Tasting the exhibit if necessary/ Communicate with stuff/commentator/ Workshop/ courses

Q11: Did the exhibition provide you with new/updated knowledge? For example, a new understanding of objects or culture.

Definitely yes

Probably yes

Might or might not

Probably not

Definitely not.

Q12: Do you think that the way you interact when you visit the exhibition will help you understand it.

Definitely yes

Probably yes

Might or might not

Probably not

Definitely not

Part 2 General questions

Q1: What is your gender?

Male Female No want to say

Q2: Age range

Under 16/ 16-24/ 25-34/ 35-44/ 45-54/ 55 or older

Q3: What is your occupation/ job title?

_______.

Q4: Which of these describes your personal salary last year?

None
Under £16,715
£16.715- £18.000
£18,000- £21,000
£21,000-£27,000
£27,000-£35,000
£35,000-£40,000
£40,000-£45,000
£45,000- 50,000
£50,000- £56,000
£56,000-£64,000
£64,000-£87,000
over £87,000

Q5: How can you get the exhibition/museum information？

Social media/ Website/ Advertisement/ Family/ friend/ Other (s)_______

Appendix B The Content of Screenshots of Raw Data Collection

Raw Data Table 1（New Designer Exhibition):

Participant NO.	Gender	Age Group	Q1:Do you always visit exhitions/museums?	Q2:Are you visiting the museum with?	Q3: What type of exhibition/museum is most attractive to you?	[illegible] interavtive exhibition or a viewing-oriented exhibition?	Q5.Waht are you impressions of the Exhibition?	Q6.What did you find the most interesting?Why?	Q7. What did you find less interesting or what you not like? Why?	Q8.What was your favourite aspect of this experience?	Q9.According to the precious question, could you please explain why you like the option?	Q10.Does the interaction help to deepen your understanding of the exhibitions/objectives?	Q11. How can you get the exhibition information?
1	Male	35-44	YES	Along Patner/friend Family School/colleges A tour-group	Art/Design	Less interaction	Very disappointing event, lacking any real innovation or impact in relation to exhibitors and the products that they displayed. Very few inspirational exhibitors, unclear as to what was being displayed and promoted	Exhibition stand presenting relevant materials relating to the development of a project. Clearly displayed, with supporting marketing literature.	Several exhibition stands with very minimal marketing materials (Empty stands with sales people that did not want to discuss their business).	Being able to look at details of the objects	Need to understand the details of the materials and objects to see if it is relevant or related to project requirements. Physical object enables a tangible physical representation and therefore it is easier to understand its relevance.	YES	Website
2	Male	25-34	YES	Along Patner/friend A tour-group	Art/Design Historical Science	More interaction	Variety of design, the wide range of idea and innovation.	the concept idea from differences designer because it can give the view of future trend and also seeing the innovative idea give me an inspiration for the future work.	some booths didn't describe the story at the first sight lead to the less attractive to audiences	Being able to look at details of the objects	the more details give the more background knowledge, learning the other perspective could create the new innovation.	YES	University
3	Female	18-24	Not always	Along	Art/Design Historical	Less interaction				Communicate with designers		Not sure	Website
4	Female	25-34	Not always	Patner/friend Family	Historical Science Special	More interaction	Bank of England Museum, perfectly secured. More suitable for children to visit.	Details and explaration of cash, such as the pattern on cash and the reason for these designs. The history to design and make money. I'd like to know the interesting historical stories in different museums.	Less interest in long stories or stories just in words.	Being able to look at details of the objects	When you look at the details and understand the organization of these details, you can understand all aspects of the overall design.	YES	Social media
5	Female	25-34	YES	School/colleges	Art/Design Historical	More interaction				Being able to ask questions about the objects whilst holding them		YES	Social media

6	Male	25-34	YES	Along Patner/friend Family	Art/Design	More interaction	The design museum was a lot more interesting in terms of how many items and the variety that was on display. It was also presented in an exciting manner, with displays in various positions; some were in conventional glass boxes but others were on the walls or hanging from the ceiling. The 3D printer being shown in action also made for a more engaging experience. The Bank of England was not as intetesting in terms of display but there was a lot more depth as it focused on history and not just technology like the Design Museum. I would have liked to have seen more artifacts from the Bank and perhaps more exploration into the future	Definitely the Design Museum because it showed a really broad spectrum of what design is amd how impacts life in many ways.	The Bank of England had a lot of old drawings of the building taking up a lot of space. Wasn't that interesting compared to other aspects of the bank.	Being able to look at details of the objects	Some things you never see in everyday life and so it was great to have the opportunity to.	YES	Advertisement
7	Male	45-54	Not always	Family	Art/Design Science	More interaction	Not interactive enough but engaging	The quality of the exhibits	The variety of exhibits. Not diverse enough	Being able to ask questions about the objects whilst holding them		YES	Website
8	Female	25-34	NO	Patner/friend	Historical Specal Geology	More interaction	Very attractive, worth visiting, a nice alternative for history learning	The way of display is as clear as a guidance for visitors.	Less interaction and few introduction	Being able to look at details of the objects	The aim of visiting a musuem is to know the idea of the designer or the details of what happened in the past. With the detials of the objects, we can really enjoy our visit in the museum.	YES	Website
9	Female	25-34	YES	Patner/friend Family School/colleges	Art/Design Historical Science	More interaction	It was intellectual, learned a lot about the ongoing research/study. Was also fascinated about how people think out of the box.	Ideas and designing of people was interesting. How they pursue different fields and trying to be different for the better and comfortable future.	No comments	Being able to ask questions about the objects whilst holding them	I was not really able to understand their work in one go. While looking at what they have made I have lot of questions, to confirm my thought about their work.	YES	Social media

10	Male	25-34	Not always	Patner/friend Family	Historical Science	More interaction	It was a very interesting exhibition with a lot of innovative designs to solve day to day problems	device that helps you to regulate your heart rate, in order to address stress problems and anxiety. It was very interesting because it have a visual aid to get your concentration. Basically you hold a device that sense your heart rate and turn it into a signal that is transmitted to a computer program. The computer program then controls a mechanical device that is able to draw circles (when your Heart rate is less than 80 beats per minute) and spikes when your heart rate goes higher than 80 beats	What I found less interesting was a stand for guitar pedals effects. I did not find that innovate at all	Being able to ask questions about the objects whilst holding them	the objects it is easier to understand wha	YES	Friend/Family
11	Female	25-34	YES	Patner/friend	Art/Design Historical Science	Less interaction	I found really insightful the fact that we could talk directly to the designers and ask them question	The venue itself was quite quirky: a common place with shops and activities inside, that was acting as a microcosm. I wasn't used to this kind of exibitions, woven into the fabric of the city.	I found the theme to be quite sad, and also some of the design projects were weak from a conceptual point of view. Some other project were insightful and could potentially impact on our future life.	Comminicate with designers	Human contact with the creator of the object. Knowing that I could have asked all the questions that I wanted and the most suitable person to give me an answer was the creator itself.	Not sure	Friend/Family
12	Male	25-34	Not always	Alone Patner/friend	Historical Science Geology	More interaction	The way they display the exhibition was good. Besides that, the majority of the project that presented an engineering component was not well design. Some of them were not event tested to see the proper functionality and just focus on the apparent	Some project where the student gets really involved in the topic before proposing any design they consult with different experts.	The design of Aerial firefighting, it seems the student was not properly advised on the design for the specific mission or at least he did not present the discussion on what that was a good option.	Comminicate with designers	In order to understand some proyect, it needed some in deep explanation.	Not sure	Friend/Family
13	Male	18-24	Not always	Alone Patner/friend Family	Art/Design Science Special	More interaction	It was such a maze, really confusing. I didnt visit a lot of exhibitions but i know for sure that they could have optimised the organisation and the arragment. Beside that, it was quite interesting to see all the stand with so many items and things displayed.	The fact that all the stands were organised but with their own display and layout of items. Even if you pass by the same stand many times in a day, you are still surprised and astonished.	I know u still need sponsors in this kind of event, but to see brands demonstrating their products is quite boring and annoying cause you're not there to see the same kind of advertising than at the TV. For me, it's the main negative point.	Being able to look at details of the objects	I like staring at things to see all the details and understand why it is like that, what's the meaning. After that, if I still need more information I will ask someone	YES	Friend/Family
14	Female	25-34	Not always	Alone Patner/friend Family	Art/Design Science Special	More interaction	It was such a maze, really confusing. I didnt visit a lot of exhibitions but i know for sure that they could have optimised the organisation and the arragment. Beside that, it was quite interesting to see all the stand with so many items and things displayed.	The fact that all the stands were organised but with their own display and layout of items. Even if you pass by the same stand many times in a day, you are still surprised and astonished.	I know u still need sponsors in this kind of event, but to see brands demonstrating their products is quite boring and annoying cause you're not there to see the same kind of advertising than at the TV. For me, it's the main negative point.	Being able to look at details of the objects	I like staring at things to see all the details and understand why it is like that, what's the meaning. After that, if I still need more information I will ask someone	YES	Friend/Family

15	Female	25-34	Not always	Alone Family	Art/Design Historical Special	More interaction	Honestly, I love it, it was a really pleasant experience, I was impressed by all the new inventions and so on.	The new focus about design products, with an special focus on the projects that were thinking to creat a circular economy. Also, I found interesting the interaction with the new articules.	I love the exhibition, but I would like to see it in an order, like: cars, people, etc, instead universities. Sometimes it was hard to change the focus.	Being able to ask questions about the objects whilst holding them	It made me to understand more the product and the inspiration for doing it.	YES	Friend/Family
16	Female	25-34	YES	Alone Patner/friend	Art/Design Special	More interaction	So many products design, some of them are very interesting and useful, and I could touch them and ask more question to the designers.	An university, their exhibition is about car design. Some students were on the scene and showed their process of making models.	Some of design product, they lack practical experience	Being able to look at details of the objects	The item that I can touch or play with, can give more impressions! When I played with it, I feel so fun! Some of the products, they only have a poster on the wall, or the products can not touch, so I just pass them to looked at others	YES	Social media

Appendix C The Content of Screenshots of Table Answer in Questionnaire in Chapter 3

Interesting Answer Q1/Q2/Q3			
Participant NO.	Interesting comment		
	Q1	Q2	Q3
3	Not always	Along	Art/Design Historical
4	Not always	Patner/friend Family	Historical; Science Special
7	Not always	Family	Art/Design Science
8	No	Patner/friend	Historical; Special Geology
10	Not always	Patner/friend Family	Historical Science
12	Not always	Alone Patner/friend	Historical; Science Geology
13	Not always	Alone Patner/friend Family	Art/Design Science Special
15	No	Alone Patner/friend	Art/Design Special

Interesting Answer Q5： What are you impressions of the Exhibition you just visiting?	
Participant NO.	Interesting comment
1	Very disappointing event, lacking any real innovation or impact in relation to exhibitors and the products that they displayed. Very few inspirational exhibitors, unclear as to what was being displayed and promoted
2	Variety of design, the wide range of idea and innovation.
7	Not interactive enough but engaging
9	It was intellectual, learned a lot about the ongoing research/study. Was also fascinated about how people think out of the box.
10	It was a very interesting exhibition with a lot of innovative designs to solve day to day problems
11	I found really insightful the fact that we could talk directly to the designers and ask them question
12	The way they display the exhibition was good. Besides that, the majority of the project that presented an engineering component was not well design. Some of them were not event tested to see the proper functionality and just focus on the apparent
13	It was such a maze, really confusing. I didnt visit a lot of exhibitions but i know for sure that they could have optimised the organisation and the arragment. Beside that, it was quite interesting to see all the stand with so many items and things displayed.
14	So many products design, some of them are very interesting and useful, and I could touch them and ask more question to the designers.

Q6:What did you find the most interesting?Why?	
Participant NO.	Interesting comment
1	Exhibition stand presenting relevant materials relating to the development of a project. Clearly displayed, with supporting marketing literature.
2	The concept idea from differences designer because it can give the view of future trend and also seeing the innovative idea give me an inspiration for the future work.
7	The quality of the exhibits
8	The way of display is as clear as a guidance for visitors.
9	Ideas and designing of people was interesting. How they pursue different fields and trying to be different for the better and comfortable future.
11	The venue itself was quite quirky: a common place with shops and activities inside, that was acting as a microcosm. I wasn't used to this kind of exibitions, woven into the fabric of the city.
12	Some project where the student gets really involved in the topic before proposing any design they consult with different experts.
13	The fact that all the stands were organised but with their own display and layout of items. Even if you pass by the same stand many times in a day, you are still surprised and astonished.
14	An university, their exhibition is about car design. Some students were on the scene and showed their process of making models.
16	The new focus about design products, with an special focus on the projects that were thinking to creat a circular economy. Also, I found interesting the interaction with the new articules.
10	One of the exhibitions was about a device that helps you to regulate your heart rate, in order to address stress problems and anxiety. It was very interesting because it have a visual aid to get your concentration. Basically you hold a device that sense your heart rate and turn it into a signal that is transmitted to a computer program. The computer program then controls a mechanical device that is able to draw circles (when your heart rate is less than 80 beats per minute) and spikes when your heart rate goes higher than 80 beats per minute.

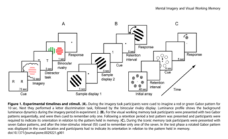
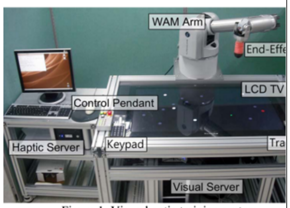
Interesting Answer Q7 :What did you find less interesting or what did you not like? Why?	
Participant NO.	Interesting comment
1	stands with sales people that did not want to discuss their business).
2	attractive to audiences
4	Less interest in long stories or stories just in words.
7	The variety of exhibits. Not diverse enough
8	Less interaction and few introduction
10	What I found less interesting was a stand for guitar pedals effects. I did not find that innovate at all
11	I found the theme to be quite sad, and also some of the design projects were weak from a conceptual point of view. Some other project were insightful and could potentially impact on our future life.
12	advised on the design for the specific mission or at least he did not present the discussion on what that was a good option.
13	I know u still need sponsors in this kind of event, but to see brands demonstrating their products is quite boring and annoying cause you're not there to see the same kind of advertising than at the TV. For me, it's the main negative point.
14	Some of design product, they lack practical experience
16	I love the exhibition, but I would like to see it in an order, like: cars, people, etc, instead universities. Sometimes it was hard to change the focus.

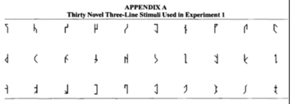
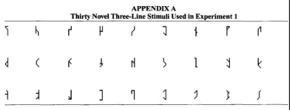
Interesting Answer Q8:What was your favourite aspect of this experience?	
Interesting comment	Participants
Being able to look at details of the objects	8
Communicate with designers	3
Being able to ask questions about the objects whilst holding them	5
Being able to compare a range of objects	1

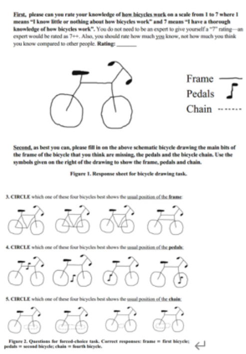
Interesting Answer Q9:According (8), could you please explain why you like the option.		
Precious options	Participant NO.	Interesting comment
Being able to look at details of the objects	1	Need to understand the details of the materials and objects to see if it is relevant or related to project requirements. Physical object enables a tangible physical representation and therefore it is easier to understand its relevance.
	2	the more details give the more background knowledge, learning the other perspective could create the new innovation.
	4	When you look at the details and understand the organization of these details, you can understand all aspects of the overall design.
	14	The item that I can touch or play with, can give more impressions! When I played with it, I feel so fun! Some of the products, they only have a poster on the wall, or the products can not touch, so I just pass them to looked at others
	13	I like staring at things to see all the details and understand why it is like that, what's the meaning. After that, if I still need more information I will ask someone
Communicate with designers	11	Human contact with the creator of the object. Knowing that I could have asked all the questions that I wanted and the most suitable person to give me an answer was the creator itself.
	12	In order to understand some project, it needed some in deep explanation.
Being able to ask questions about the objects whilst holding them	9	I was not really able to understand their work in one go. While looking at what they have made I have lot of questions, to confirm my thought about their work.
	4	When you look at the details and understand the organization of these details, you can understand all aspects of the overall design.
	16	It made me to understand more the product and the inspiration for doing it.
	10	Because when you are able to interact with the objects it is easier to understand what is the purpose of it, and see how it works.
Being able to compare a range of objects	None	

Interesting Answer Q10 : Does the interaction help to deepen your understanding of the exhibitions/objectives?	
Interesting comment	Participants
YES	13
NOT SURE	3
NO	0

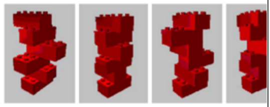
Appendix D Summary of Fifty Methods of Experiments of Chapter 4

NO.	Method	Pic	Pro	Con	Memory Type
1.	The causal luminance disruption experiments				Iconic Memory
2.	Built a custom visuo-haptiv traing system 4 training methods (V)visual display (E)Visuak disolay with enactment (G)visual display with active guidance (F)visual display with virtual fixture Experimental: 1. pretest session 2. Main session 3. Post-test session (1,2. one day; 3. after 24h	 Figure 1. Visuo-haptic training system.			Haptic Memory

NO.	Method	Pic	Pro	Con	Memory Type
3	2d patterns and 3d object **Experiment1(2D patterns)** ***The visual and haptic perceptual identification** ***Explicit recognition tests** 1.Half of all participants studied the shapes visually first, and half studied them haptically first. **2.**The 30 stimuli were divided in to 3 groups and each group was rotated through visual, haptic and non studied conditions to achieve counterbalancing. 3.at test, the subjects were presented with 20 studied and 10 nonstudied shapes in five different random orders to control for order effects. Subjects would be given brief presentations of shapes and they had to draw the shapes correctly after each	 			Haptic Memory Iconic Memory

NO.	Method	Pic	Pro	Con	Memory Type
4.	Experiment 1: he task required the serial recall of sequences of nine random digits selected without repetition by an ACORN microprocessor and successively presented on a TV screen at a speed of 750 milliseconds. The digit duration was 500 milliseconds with an interval of 250 milliseconds between digits. The subjects heard the word "READY" which occurred 3 seconds before the onset of each series. They were allowed to respond immediately after the last item, were instructed to recall the items in the order presented, and were allowed 15 seconds to do so.				Iconic Memory
5.	The science of cycology: failures to understand how everyday object work 1. Experiment 1: Non-experts who were not told what the study as testing 2. Experiment 2: Non-experts informed that their functional knowledge was being tested 3. Experiment 3: Cycling experts who were not told what the study was testing		Each experiment is interesting and purposeful.		Echoic Memory

<table>
<tr><th>NO.</th><th>Method</th><th>Pic</th><th>Pro</th><th>Con</th><th>Memory Type</th></tr>
<tr><td>6.</td><td>1: Experimental studies on cross-modal recognition

In experiments, we measured the effects of viewpoint on visual, haptic and cross-modal recognition. We used a set of unfamiliar objects made from six identical red Lego bricks. All objects were presented in a fixed position in front of the participant. Each object had a different configuration of these bricks, and hence we controlled for differences in size, texture and colour, which may and recognition performance in one modality only. Participants performed a recognition memory task in all the experiments. First, they were required to learn four target objects in a sequential order either visually (for 30 s each) or haptically (for 1 min each). A pilot study revealed that haptic exploration time needed to be longer than visual exploration time in order to achieve equivalent performance across these modalities. The objects were placed behind a curtain during the haptic condition and participants placed their hands underneath the curtain to touch the objects. We gave no explicit instructions on how to learn the objects except that the object should not be moved.</td><td>
Fig. 4. An illustration of the type of objects used in our ha
visual object recognition experiments.</td><td></td><td></td><td>Iconic Memory

Haptic Memory</td></tr>
</table>

<table>
<tr><th>NO.</th><th>Method</th><th>Pic</th><th>Pro</th><th>Con</th><th>Memory Type</th></tr>
<tr><td>7.</td><td>Subjects attempted to recognize simple line drawings of common objects using either touch or vision. In the touch condition, subjects explored raised line drawings using the distal pad of the index finger or the distal pads both of the index and of the middle fingers. In the visual condition, a computer-driven display was used to simulate tactual exploration. By moving an electronic pen over a digitizing tablet, the subject could explore a line drawing stored in memory; on the display screen a portion of the drawing appeared to move behind a stationary aperture, in concert with the movement of the pen. This aperture was varied in width, thus simulating the use of one or two fingers.</td><td>Table 1. Number of correct responses (out of six) and average response latencies for visu
tactual recognition with the narrow field condition.
<table>
<tr><th>Picture</th><th>Vision</th><th></th><th>Touch</th><th></th></tr>
<tr><th></th><th>correct responses</th><th>response latency/s</th><th>correct responses</th><th>response latency/s</th></tr>
<tr><td>Lightbulb</td><td>6</td><td>65</td><td>4</td><td>82</td></tr>
<tr><td>Pencil</td><td>6</td><td>27</td><td>4</td><td>68</td></tr>
<tr><td>Envelope</td><td>2</td><td>94</td><td>3</td><td>102</td></tr>
<tr><td>Glove</td><td>3</td><td>99</td><td>4</td><td>92</td></tr>
<tr><td>Hanger</td><td>1</td><td>107</td><td>5</td><td>70</td></tr>
<tr><td>Screw</td><td>4</td><td>62</td><td>2</td><td>120</td></tr>
<tr><td>Sweater</td><td>2</td><td>105</td><td>0</td><td>118</td></tr>
<tr><td>Key</td><td>3</td><td>109</td><td>2</td><td>102</td></tr>
<tr><td>Spoon</td><td>2</td><td>85</td><td>5</td><td>62</td></tr>
<tr><td>Clothespin</td><td>1</td><td>115</td><td>0</td><td>120</td></tr>
<tr><td>Carrot</td><td>1</td><td>114</td><td>4</td><td>104</td></tr>
<tr><td>Comb</td><td>5</td><td>66</td><td>4</td><td>68</td></tr>
<tr><td>Knife</td><td>1</td><td>77</td><td>2</td><td>97</td></tr>
<tr><td>Sock</td><td>1</td><td>101</td><td>1</td><td>112</td></tr>
<tr><td>Glasses</td><td>5</td><td>79</td><td>2</td><td>106</td></tr>
<tr><td>Scissors</td><td>6</td><td>42</td><td>4</td><td>89</td></tr>
<tr><td>Screwdriver</td><td>4</td><td>67</td><td>1</td><td>113</td></tr>
<tr><td>Ashtray</td><td>0</td><td>120</td><td>1</td><td>120</td></tr>
<tr><td>Candle</td><td>6</td><td>72</td><td>1</td><td>110</td></tr>
<tr><td>Whistle</td><td>1</td><td>118</td><td>0</td><td>120</td></tr>
<tr><td>Cup</td><td>5</td><td>83</td><td>2</td><td>83</td></tr>
<tr><td>Bowl</td><td>4</td><td>89</td><td>6</td><td>66</td></tr>
<tr><td>Hammer</td><td>2</td><td>111</td><td>5</td><td>99</td></tr>
<tr><td>Lock</td><td>0</td><td>120</td><td>1</td><td>120</td></tr>
</table>

Figure 1. The pictures used in the experiment.</td><td></td><td></td><td>Iconic Memory

Haptic Memory</td></tr>
</table>

NO.	Method	Pic	Pro	Con	Memory Type
8.	Stimuli consisted of seven scene-regions, each bounded by a frame. The regions and their dimensions are shown in Fig. 1. Two stimuli and the remaining five stimuli were in another room, connected by a small hallway with a chair that served as a waiting area. Scene-regions were positioned so that vision participants could see only one scene region at a time. Two different types of frames were used for the visual and haptic study conditions	136 H. Intraub et al. / Cognition 138 (2015) 132–147  Fig. 1. The seven scene-regions in order of presentation: (a) Sink: 20" × 17" (51 cm × 43 cm), (b) dog: 24" × 24" (61 cm × 61 cm), (c) s (38 cm × 48 cm), (d) baby: 18" × 18" (46 cm × 46 cm), (e) cabinet: 17" × 23" (43 cm × 58 cm), (f) tools: 19" × 14" (48 cm × 36 cm), (g) k (56 cm × 41 cm).	Can be used of the way of touch item with boundaries.		Iconic Memory Haptic Memory
	because of the different nature of the moralities. For the visual study, it was important that the frame lay flat on the floor so that the edges would not occlude part of the view. Also, it was critical to cover the surrounding space just outside the boundaries so that the participant's peripheral vision would not include visual information about the studied surface beyond the				
	boundaries. In the visual study conditions, the bounding frame was a rectangle constructed of flat wooden strips to which black cloth was attached. For haptics, the flat frame used for vision does not create a sufficient boundary to prevent participants from accidently moving their hands outside the stimulus region.	 2. Visual exploration (left) and haptic exploration (right) of the "dog" scene. (All boundaries were ren			

<table>
<tr><th>NO.</th><th>Method</th><th>Pic</th><th>Pro</th><th>Con</th><th>Memory Type</th></tr>
<tr><td>9</td><td>Lessons were organized in different group sizes with a maximum of five, dependent on school-related resources. Although there was variation in the specific teaching strategies between schools, all children in the target group received basic skills training, which included singing, rhythm (clapping and percussion) and some ear training (pitch and rhythm recognition) from first grade on (children between 6 and 7 years of age). The instrumental instruction was delivered from second to fourth grade (children between 7 and 10 years of age) by professional teachers from public music schools. Results were assessed by raw means for each of the four sub tests and standardized IQ scores adapted for age. The socioeconomic background was determined by variables related to parental education and income. This information was acquired through</td><td>
Table 2. Means (and SD) of working memory assessment data for music and natural science groups at three time points (T1–T3).
<table>
<tr><th>Measures</th><th>Music (n = 25)</th><th></th><th></th><th>Natural sciences (n = 25)</th><th></th><th></th></tr>
<tr><th></th><th>T1</th><th>T2</th><th>T3</th><th>T1</th><th>T2</th><th>T3</th></tr>
<tr><td>Visuospatial sketch pad</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Corsi Block</td><td>3.87 (.55)</td><td>3.85 (.83)</td><td>4.57 (.70)</td><td>4.26 (.83)</td><td>4.25 (.68)</td><td>4.57 (.78)</td></tr>
<tr><td>Matrix Span</td><td>4.17 (.84)</td><td>4.70 (1.10)</td><td>5.00 (.98)</td><td>4.35 (1.13)</td><td>4.77 (1.10)</td><td>4.82 (1.45)</td></tr>
<tr><td>Phonological loop</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nonword Recall</td><td>16.24 (2.86)</td><td>18.68 (3.01)</td><td>20.04 (2.54)</td><td>14.20 (3.54)</td><td>15.84 (3.58)</td><td>14.36 (3.53)</td></tr>
<tr><td>One-Syllable Word Span</td><td>3.80 (.56)</td><td>4.21 (.57)</td><td>4.65 (.68)</td><td>3.79 (.48)</td><td>3.85 (.44)</td><td>3.80 (.71)</td></tr>
<tr><td>Central executive</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Counting Span</td><td>3.03 (.56)</td><td>3.57 (.70)</td><td>3.85 (.66)</td><td>3.13 (.74)</td><td>3.44 (.63)</td><td>3.42 (.60)</td></tr>
<tr><td>Color Span Backwards</td><td>2.85 (.81)</td><td>3.30 (.96)</td><td>3.63 (.82)</td><td>2.82 (.81)</td><td>3.13 (.75)</td><td>3.19 (.62)</td></tr>
<tr><td>Complex Span</td><td>3.08 (.46)</td><td>3.45 (.54)</td><td>3.89 (.79)</td><td>3.07 (.62)</td><td>3.27 (.70)</td><td>2.99 (.57)</td></tr>
</table>
</td><td></td><td></td><td>Echoic Memory</td></tr>
</table>

Section Break (Next Page)

<table>
<tr><td></td><td>questionnaires and telephone interviews with the parents. Musical background was assessed particularly with respect to extra-curricular activities including instrumental music training in the control group.

Seven subtests from a standardized and computerized working memory battery were used in this study. They were designed to assess phonological loop, visuospatial sketchpad and central executive, according to Baddeley's working memory model.</td><td></td><td></td><td></td><td></td></tr>
</table>

NO.	Method	Pic	Pro	Con	Memory Type
10	People were asked to: draw a penny from unaided recall; draw a penny given a list of its visual features; choose from among a list of possible features those which do appear on a penny; indicate what was wrong with an erroneous drawing of a penny; and select the correct representation of a penny from among a set of incorrect drawings. **Experiment 1:** The purpose of the first experiment	TABLE 1 FEATURES IDENTIFIED FOR SCORING PURPOSES IN EXPERIMENT 1 Top side Head "IN GOD WE TRUST" "LIBERTY" Date Bottom side Building "UNITED STATES OF AMERICA" "E PLURIBUS UNUM" "ONE CENT" MEMORY FOR A COMMON OBJECT  FIG. 1. Examples of drawings obtained from people who tried to reproduce a penny from memory.			Haptic Memory
	was to see how accurately people could reproduce a penny through unaided recall. **Experiment 2:** The purpose of Experiment II was to collect some data on memory for location that would be independent of memory for content. **Experiment 3:** Twenty new subjects (adult U.S. citizens) were given a list of 20 features. Their task was to indicate with respect to each feature				

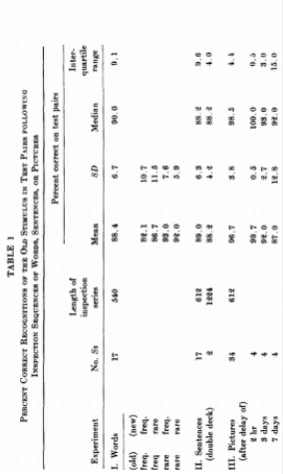
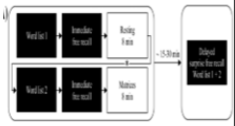
NO.	Method	Pic	Pro	Con	Memory Type
11.	**Experiment 1: Words** **Stimuli:** The basic population of stimuli consisted of 600 English common nouns and adjectives each of which was between five and seven letters in length. **Experiment 2: SENTENCES** **Stimuli:** The initial population of stimuli consisted of 1360 short English sentences. (Examples: "A dead dog is no use for hunting ducks." "The colt reared and threw the sick rider.") The sentences were typed on separate 3 X 5-in. cards as before. **Experiment 3: PICTURES** **Stimuli:** The basic population of stimuli consisted of 748 coloured pictures each of which was glued on a separate 5 X 8-in. white card. The principal criteria for selection of stimuli for this population, while entirely subjective, were intended to ensure that the pictures would be both (a) individually of high salience and memorability and (b) collectively of low similarity and confusability.				Iconic Memory Echoic Memory

TABLE 1
PERCENT CORRECT RECOGNITIONS OF THE OLD STIMULUS IN TEST PAIRS FOLLOWING INSPECTION SEQUENCES OF WORDS, SENTENCES, OR PICTURES

Experiment	No. Ss	Length of inspection series	Percent correct on test pairs: Mean	SD	Median	Inter-quartile range
I. Words	17	540	88.4	6.7	90.0	9.1
(old) (new)						
freq. freq.			82.1	10.7		
freq rare			86.7	11.5		
rare freq.			93.0	7.6		
rare rare			92.0	5.9		
II. Sentences	17	612	89.0	6.3	88.2	9.6
(double deck)	2	1224	88.2	4.2	88.2	4.0
III. Pictures	34	612	96.7	3.8	98.5	4.1
(after delay of)						
2 hr	4		99.7	0.5	100.0	0.5
3 days	4		92.0	2.7	93.0	3.0
7 days	4		87.0	12.8	92.0	15.0

NO.	Method	Pic	Pro	Con	Memory Type
12	**Drawing as an encoding strategy** **Experimental 1:** Selected 89 words and making sure that all words can be easily drawn. After the prompt starts, 30 words are randomly given, 15 pictures are drawn, and 15 words are written. All words are given as part, and the latter part is added to the participants. Next phase of the experiment: recall as many words as they can(either written or drawn, 2 min)		Can be used, but the amount of words may be reduced, and the ages mentioned in the article are grouped by age, I think it is OK to find an average age. Combine some real objects		Iconic Memory
	Experimental 2: compare the effectiveness of drawing as an encoding tool,to an elaborative task, which we designed to elicit a deep LoP (the semantic meaning of a word)	30 words was divided into three lists of 10-words each (10 to be drawn, 10 to be visualized, 10 to be written)			

NO.	Method	Pic	Pro	Con	Memory Type
13.	**Free recall of real-world scenes, and quantify the content of memory using a drawing task.** stimuli from 30 varied scene categories (three images per category)°(chosen to contain a high memorable, a medium memorable, and a low memorable image)		Can be used, but need to dived diff period of time(vision/language/drawing)		Iconic Memory
	Delayed Recall experiment(n=30) five parts in order: (1) study phase, (2) digit span task, (3) free recall phase, (4) cued recall phase,(5) recognition phase.				
	Verbal Free Recall experiment (Category Drawing experiment)				
	Category Drawing experiment (n=15 were asked to draw images based on the category names used in the Delayed Recall experiment, presented in a random order.)				
	The Image Drawing experiment (n=24 were asked to draw a subset of the images used in the study phase of the Delayed Recall experiment, while looking directly at them.)				
	Immediate recall experiment (n=30 performed a recall task where they were asked to draw each image from memory immediately after viewing it, rather than after a delay.)				

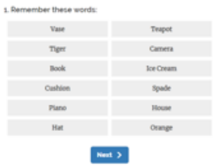
NO.	Method	Pic	Pro	Con	Memory Type
14.	**large numbers of colour photographs with a common motif was studied using pictures with two levels of informative cues: original photographs, and edited pictures.** Memory was tested at four different time intervals, 0.5 hours, 2 hours, 2 days and 7 days.			Without reference, I feel that the visual differences are too detailed and may not be suitable.	Iconic Memory
15.	**Test-Enhanced Learning Taking Memory Tests** In two experiments, students studied prose passages and took one or three immediate free-recall tests, without feedback, or restudied the material the same number of times as the students who received tests. Students then took a final retention test 5 min, 2 days, or 1 week later. When the final test was given after 5 min, repeated studying improved recall relative to repeated testing.		Can be used, can refer to some text information in the exhibition, according to different topics, let readers read. Then repeat the experiment to test the participants' memory according to the planned time range.		Echoic Memory
16.	**Word list / Post learning rest** (1) retain a first word list; (2) immediately recall the words of this list; (3) perform an 8-min post-encoding condition, where they either rested wakefully or completed a distraction task; (4) retain a second word list; (5) immediately recall words of this second list; (6) perform either a distraction task or a rest condition; a(7) finally complete a surprise free recall test.			Not used17.	

NO.	Method	Pic	Pro	Con	Memory
17.	**The study utilized a level of visual detail (2) by** **olfactory stimulation (2) by ambient auditory** **stimulation (2) by tactile stimulation (2) between subject's factorial design.** **questionnaire** had 14 questions that related to the sense of presence. 1.the location of items in the office 2.general layout of the office space 3.five were filler/catch items. 4.four spatial layout questions and five object location questions.	 Figure 5. Large office in high detail  Figure 6. Large office in low detail  Figure 7. VR Setup	Very good experiments on the senses, can be used both virtual spaces and display space, but the virtual space of the device needs to be prepared. Questionnaire questions can be used in the experiment.		Tactile,olfactory audio,visual sensory
18.	**The utility of multi sensory educational tools** In the visual condition The auditory condition The audiovisual condition			Could be review	Echoic Memory
19.	**Feel 32 complex plastic geometric objects and were tested in a signal-detection framework to same or distractor items. (CG) the subject in the control group. (TIG) the tactile interference group. (VCIG) the verbal counting interference group**		Yes, could be use		**haptic memory**

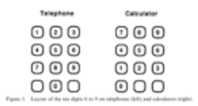
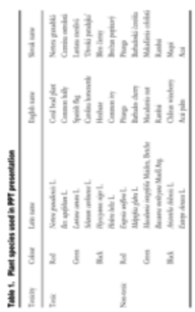
NO.	Method	Pic	Pro	Con	Memory Type
20.	**Visual illustrations as well as taking tests (vs. restudying) is beneficial for learning** Recall and transfer tests were conducted after some few minutes and again after one week. Questionnaire Basic information		retention interval interaction Can learn from part **learning，recall and transfer** After the memory test, the recall and transfer test will continue in a fixed time. (This method is suitable for detecting when people are watching the contents of the exhibition, the content is delivered)		
21.	Shown 2,560 photographic stimuli or 10 sec each:: their recognition memory was then tested, using a two-alternative forced-choice task. two-alternative forced-choice task: **The first two examine** memory for approximately 1,000 and 2,500 pictures, respectively. **The third examines** the effects of duration of Viewing. **The fourth** concerns the effects of reversing the stimuli between the learning and test sessions, and of the memory for orientation as well as identity of pictures.			It takes more than 2 hours for a test. I don't think participants will have much patient for the test, it will loss some valid information. Moreover, too many pictures are not easy to find	Iconic memory

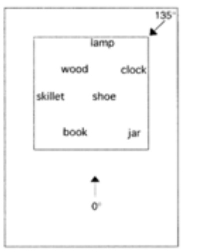
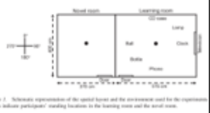
NO.	Method	Pic	Pro	Con	Memory Type
22.	The battery consists of six categories of tests that are assumed to measure: spatial comprehension, short-term memory, object identification, raised shape identification, sequential scanning, and texture and material discrimination.	**Spatial comprehension** Spatial orientation; Spatial location   **Spatial comprehension** Spatial orientation; Spatial location    **Discrimination skills** Texture discrimination ; Shape discrimination; Size discrimination.	It can be tested in combination with 2D and 3D. The picture and the object are the same, then after the visual test, touch experiment or other sensory experiment, but the vision and touch can not be performed simultaneously	It's just a tactile test for people with visual impairments that has nothing to do with memory persistence. But a few of the experiments inside can be used for reference, better combined with memory testing.	Haptic memory

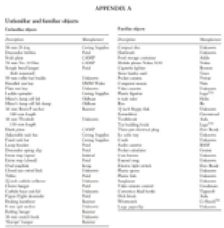
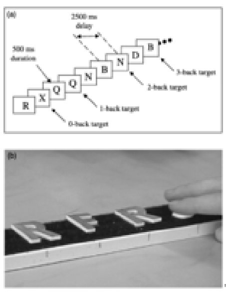
NO.	Method	Pic	Pro	Con	Memory Type
23.	**Observers were presented with pictures of 2,500 real world objects for 3 s each.** The experiment instructions and displays were designed to optimize the encoding of object information into memory. 1. observers were informed that they should try to remember all of the details of the items. 2.objects from mostly distinct basic-level categories were chosen to minimize conceptual interference. 3. memory was tested with a two-alternative forced-choice test, in which a studied item was paired with a foil and the task was to choose the studied item, allowing for recognition memory rather than recall memory		Good		Iconic memory
24.	Four lists of words were used for each condition for a total of 8 lists.			Not good	Iconic memory Echoic Memory
25.	Seven users interacted with a small version of the CORONA audio space.				Iconic memory Echoic Memory
26.	**the span-of-perception experiment**. Its aim is to determine the maximum number of objects a person can take in at a glance, the objects being dots, letters, digits, words, etc.	Fig. 1 — Typical array of letters, bar marker and circle indicator.			

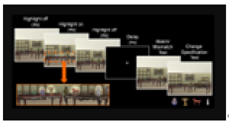
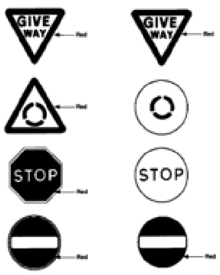
NO.	Method	Pic	Pro	Con	Memory Type
27.	Participants will interact with the installation by touching one of four touch-sensitive panels. Light and sound (outputs) are used to indicate which panel should be touched (inputs).	 **Photo 1 Vision of the control unit**  **Photo 2 Concept of 4 touch-sensitive panels for an outdoor gallery**	Could be review		
28.	**Four experiments are reported which examined memory capacity and retrieval speed for pictures and for words.** A population of 11,000 photographic slides was first assembled			Boring, too much pictures have to learn and remember	
29.	Use pictures and sound senses to make people meet the types of animals		Maybe useful		
30.	Read the following list only, concentrating briefly for a few seconds on each word. Then, click the **Next** button below the words.  	 		not	
31.	The stimulation of the participants' olfactory system. (5min test) the experimental group was presented with seven jars containing odors. The control group was presented with seven jars containing no odors.Each participant was given a word to associate with each jar that they smelled, and the number of words that each participant could memorize and associate	 TABLE 1 List of Odorants and Their Associated Words Odor #/ Odor Name/ Associated Word 1. Chamomile Green Tea/ Advertise 2. Strawberry Kiwi Fruit Tea/ Piano 3. Lapsang Souchang Tea/ Vegetarian 4. Thai Tea & Jasmine Olfactory Sachet/ Condense 5. Incense Stick/ Editorial 6. Brandy Cognac Tea/ Frontier 7. Thai Chicken Spice, Cinnamon, & Muling Spice/ Skeleton	The use of the odor memory method is very good. Because there is very little testing about odor		

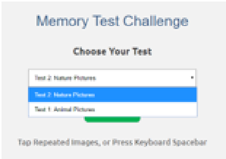
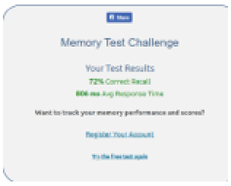
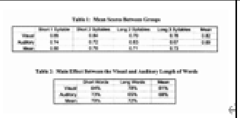
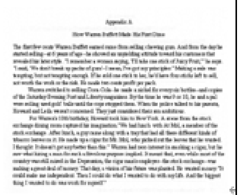
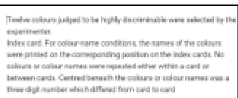
NO.	Method	Pic	Pro	Con	Memory Type
32.	The effect of labels on recognition and identification of odours over time was assessed. presented 20 odours; half of the participants were also told a name for the odour as a label. Five min. and 60 min. later, all participants were given 20 odours (10 from the original set, 10 new) and asked whether each odour was new or old (odour recognition). The group given labels was also asked to recall the label provided (odour identification). Analysis indicated a significant effect of time on recognition. Significantly more odours were recognized at 5 min. than 60 min.		good		
33.	Spatial learning was measured with a pointing task and a drawing task. Map building location call and drawing. Participants are familiar with the map given by a tool and are familiar with the location of the building. Draw the indicated position by drawing. Experiment 1 relies on the resources of the visual space canvas, and Experiment 2 relies on speech repetition.			a little complicated	
34.	**Memory for common objects: brief intentional study is sufficient to overcome poor recall of US coin features** Method Design We used a mixed factorial design with two between-subjects factors — test order condition (penny-first or dime-first) and retention interval group (immediate or delayed)— and one within-subjects factor— coin (penny and dime). Eight participants were in each of the four subsets defined by the two between-subjects factors. The effects of test order condition are not considered here.	 Figure 1. The four faces of the Mercury dime and the US Penny	Everyday items Culturally informed background With words, pictures, numbers and meanings Can be observed with multiple senses		

NO.	Method	Pic	Pro	Con	Memory Type
35.	**Map cognition experiment and space layout design** Participants in the exhibition which was designed, time limited to 30 minutes, 14 pictures and exploration of space. There is no restriction on any exhibition route, participants are free to play, just need to read the picture. Text After the exhibition, the participants placed the position of the photo according to the memories in the given p plan. Then compare with the actual picture position	  	Very consistent with research, combining spatial locations with memory testing, although true testing is unlikely to occur in similar art galleries or galleries, but other memory tests can be combined. And don't feel bored, just like the game, participants may be more willing to spend time doing it.		
36.	**sentence recall** 20 sentences, word lists, and probe words had been constructed. Each sentence included a target noun which was always its most recent word. Sentences, word lists, and probe words were presented either visually via RSVP or auditorily. Presentation time with RSVP was 250 ms per word in the list and 200 ms per word in the sentence, auditory presentation times were approximately the same	 			
37.	Memory for the layout of the ten digits 0 to 9 on the keypads of push-button telephones and calculators was investigated in five experiments.	 	Iconic memory, Hapitc memory. Auditory memory (might use sound)		
38.	A set of 12 colour photographs of fruits (The set of plants was selected so that there would be equal numbers of plants that were toxic and non-toxic to children and equal numbers of plants that have red, green and black fruits.) The oral presentation lasted approximately 20 minutes and was repeated three times (each class received the same presentation) The surprise retention test (hereafter test) consisted of three questions: (1) Naming (Do you Remember the name of this species?); (2) Toxicity (Are fruits of this plant toxic or not?); and (3) Occurrence (Where does this species occur?).	 	First, we can classify the fruit according to the color and convert the 2D picture mode in the article to a real object, but other ways of retaining the word, but only a single English language. Memory retention test And also Interview participants and how to remember the type of fruit. (is based on the color, shape or word of the fruit)		Iconic memory/language

NO.	Method	Pic	Pro	Con	Memory Type
39.	**Words recall,Modality effect** participants were asked to rate 30 unrelated words in one of three conditions. In the survival condition, words were rated as relevant or irrelevant to a survival scenario. Each participant was asked to imagine that he or she was stranded in the grasslands of a foreign land, without basic survival materials; the task was to rate how relevant each word might be to finding steady supplies of food and water and protection from predators. Time：30min/per	3 tasks 1. Survival 2. Moving 3. Pleasantness	very effective for [redacted]	Only language sense, perhaps you can record words and connect with visual senses	Verbal memory
39.40 is related to verbal memory, similarly, one is word recall, one is sentence recall (including word key words and memories). In the exhibition, the language form of the text will also appear, and it will become part of the visitor's memory.					
40	Experiment 1 -20 sentences, word lists, and probe words had been constructed (include a target noun) Verbatim recall Experiment 2- base on 1 , add gist recall Auditory presentation Visual presentation		German can be replaced by Chinese Auditory presentation Visual presentation Oral recall Written recall		Verbal memory Oral recall Written recall
41.	Spatial memory--- egocentric experience In 4 experiments, the authors investigated spatial updating in a familiar environment. Participants learned locations of objects in a room, walked to the center, and turned to appropriate facing directions before making judgments of relative direction or egocentric pointing judgments.	 One of the layouts used by Shelton and McNamara (2001	Contact with the design memory of the exhibition space, please refer to		spatial memory
42.	**The procedure of the experiment was divided into** **a learning and a testing phase.** Participants entered the learning room and were given unlimited time to visually inspect the various objects it contained.				
	Learning the species to learn where to place items based on visual and auditory learning Then put on the blindfold and go to another room. Under limited conditions, perceive the direction of the space and point out where the object is located.				

NO.	Method	Pic	Pro	Con	Memory Type
43.	Experiment 1--- encoding Experiment 2 --- retrieval To examine mental representation of familiar objects in visial/haptic crossmodal memory **EX1: Interference effects at encoding** A total of 32 familiar and 32 unfamiliar objects were selected.The familiar objects were everyday items of household or personal use, and the unfamiliar objects were items or component parts of caving or climbing equipment (Appendix A)	 APPENDIX A	Tactile and visual cross test		
	Each participant performed four types of study–test sequence, which were counterbalanced: visual encoding followed by haptic recognition and vice versa, once with familiar objects and once with unfamiliar objects. Use of objects as targets and distractors was counterbalanced. participants encoded **unfamiliar objects** haptically for 4 seconds and visually for 2 seconds. **Familiar objects** were encoded haptically for 2 seconds and visually for 1 second.				
44.	**Tactile working memory capacity, measured by letter recognition and letter memory** In the visual task, letters were presented on a computer screen and in the tactile task, plastic letters embedded on a board were explored tactually.	The visual n - back task was computerized (PC MEL Professional Version 2, Psychology Software Tools, Inc.) with automatic randomization of the letter sequences.			
					
45.	Experiment 1 Animacy effect in free recall with words （used an incidental rather than an intentional encoding memory task.） Experiment 2 Animacy effect in free recall with pictures Experiment 3 Experiment 3: The animacy effect in recognition with words				

NO.	Method	Pic	Pro	Con	Memory Type
46.	Eight rendered scenes (eg, garage, beach), were created using Punch. Eight of the objects embedded in each scene were designated "critical items," and eight distinct exemplars of these scenes were created by changing the locations of these items within the scene context. Each trial began with the presentation of a scene for 10 s followed by a 4 s delay period. The first was a global match/mismatch (or change detection) question, which prompted participants to indicate whether the test picture was the same as the one that they had just studied or was a manipulated version of that picture (ie, "Is everything in this scene the same as the previous one?").	 Home Design Software 	can set up an experiment, such as virtual and realistic scene memory comparison		
	Following the first button press, the initial question was replaced with a second question that required participants to identify the item that had changed locations (ie, "Which of the following has moved or might have moved?").				
47.	**Generalizing everyday memory: signs and handedness** **Memory for frequently encountered road signs was investigated.** **Experiment 1** Each participant was provided with a red and a black pen and was instructed to draw from memory the current British versions of four different traffic signs. **Experiment 2** Each participant was tested using a question book-let with successive items printed on separate pages.	 Figure 1. The four signs used in Experiment 1 (left) and the features recalled by 40% or more of the participants (right).	● A great memory experience for the driver. ● For those who are not driving, memory recall can be done after training ● Signs for everyday life ● Homemade standards can be prepared and will involve a lot of sensory interaction		
	After the memory probes, which were part of a larger session, handedness was elicited as follows: "Would you describe yourself as left-handed or right-handed? In particular, which hand do you use for drawing?" Participants then completed the handedness questionnaire. **Experiment 3:** participants were asked to draw any figure walking and any figure digging, with a pattern of results similar to that of Experiment 2.				

NO.	Method	Pic	Pro	Con	Memory Type
48.	 were shown a word for three seconds, then shown the next word. After each list was shown, the subjects were asked to recall the words they remembered. The same procedure was used for the auditory condition; the auditory condition consisted of reading words from a list to the participants instead of the words being shown. After the experimenter read each of the auditory lists, the subjects were asked to recall what they	 words used in the auditory section. The lists were comprised of 10 short l-syllable words, 10 short 2-syllable words, 10 long 2-syllable words, and 10 long 3-syllable words. A stopwatch was used to ensure proper exposure to each word.	Short-term memory. Words memory		
	remembered. The participants had 3 seconds in which to process each word. The participants were asked to either look or listen to each word.				
49.	There were four groups in our study, two of which heard an article, and two of which read an article. All groups were then given a post test to assess their recall. Two of the four groups took an immediate post test, and the other two took a delayed post test 45 minutes after hearing or reading the article. Visual learning outperformed auditory learning in both the immediate post-test condition, as well as in the delayed post-test condition			Much like the memory recall of a previous verbal text, this Journal gave the exact content of the article.	
50.	Effects of colour on naming and recognition of objects	Material	Easy to remember colours		
	2 tasks 1. Remembering colors (or color names) 2. Counting numbers	Twelve colours judged to be highly discriminable were selected by the experimenter. Index card. For colour-name conditions, the names of the colours were printed on the corresponding position on the index cards. No colours or colour names were repeated either within a card or between cards. Centred beneath the colours or colour names was a three-digit number which differed from card to card	Simple Short-term memory		

Appendix E Questionnaire for Cyclical Multi-sensory Memory Experiment 1: Generally Understood: Who were not Told What the Study was Testing

Block 1

This is a memory experiment about remembering objects in our daily life, which is related to a PhD project. This questionnaire aims to understand everyone's ability to observe and remember common things in life. Please fill in the questionnaire directly. Do not try to find this item and then do the questionnaire.

The questionnaire is divided into three sections and 12 questions in total. It takes about 3-4 minutes.

Thank you for your participation!

Section 1：Personal questions

Q1: What is your gender?

Q2: What is your age range?

Q3: What nationality are you?

Q4: How long have you lived in the UK?

Q5: Which hand do you usually write or draw?

A. Left hand

B. Right hand

C. Both hands can be

Q6: Which method of payment are you used to in your life?

A. Only cash

B. Only credit card

C. Cash and credit card

D. PayPal

E. Others_______

Q7: How long has it been since you last paid in cash?

A. Half month

B. One month

C. Less three months

D. Less six months

E. Less one year

F. Others________

Section 2: Common objects in our daily life

Q1: Can you rate your knowledge of how much you know about the history of the £1 coin? From 1 to 10 means "I know little or nothing about the design history of the £1 coin", and ten means “I have a thorough knowledge of the 1 pound coin”).

A. Extremely good

B. Somewhat good

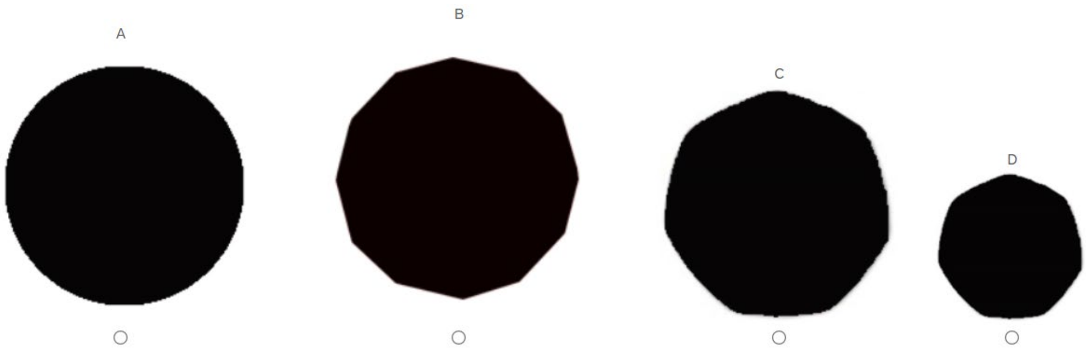
C. Neither good nor bad

D. Somewhat bad

E. Extremely bad

Block 3：The forced-choice task

Q1: Which option do you think it is the shape of £1 that we currently use？



Q2: Which option do you think is a £1 which we currently use？

A

B

C

D

Q3: What is the colour of the £1 we recently used?

A. Silver

B. Copper

C. Gold

D. Silver and Copper

E. Silver and Gold

Q4:Do you know that the coin is made by that company?

(Please write down the company name if you know.)

A. Yes_________
B. Maybe
C. No

Block 4

Thank you for your participation!

If you have any questions, please contact me by email: Yijing.Ji@cranfield.ac.uk.

Appendix F Questionnaire for Cyclical Multi-sensory Memory Experiment 2: Short-term memory (Text and pictures as media)

Block 1 Learning section

This experiment is based on the results of Memory Experiment 1 and aims to test the short-term memory of participants through pictures and question-and-answer methods.

The whole survey will take you 4-5 minutes. There are three parts in total. The first two parts have time limits. Please observe the pictures according to the time standard. There are a total of 12 questions and answers at the end.

Thank you for your participation.

Q1

This question lets you record and manage how long a participant spends on this page. This question will not be displayed to the participant.

01 00

Timing

These page timer metrics will not be displayed to the recipient.

First Click	0 seconds
Last Click	0 seconds
Page Submit	0 seconds
Click Count	0 clicks

00 55

Q1: The coin's design reflects the United Kingdom's heritage and superb craftsmanship. The coin is produced by the Royal Mint using cutting-edge technology. It also features a new design. This shows the English rose. The Welsh League. The Scottish thistle and the Northern Irish shamrock emerged from one stem within a royal Coronet. The Queen features the fifth coin portrayed by Her Majesty the Queen. The new one-pound coin has different dimensions, and the round pound coin is lighter, 8.75 grams. It is 2.8 millimetres. It is slightly wider. The maximum diameter is 23.43 millimetres.

This is a disturbing section.

This is disturb section.
It will take you 30 second, 3 parts in total. Please look and read all the information we give.

→

Q1

This question lets you record and manage how long a participant spends on this page. This question will not be displayed to the participant.

10

Timing

These page timer metrics will not be displayed to the recipient.

First Click	0 seconds
Last Click	0 seconds
Page Submit	0 seconds
Click Count	0 clicks

09

	1986 1991	**Edge Inscription:** DECUS ET TUTAMEN **Designed by:** Leslie Durbin
	1987 1992	Oak Tree and royal diadem representing England. **Edge Inscription:** DECUS ET TUTAMEN **Designed by:** Leslie Durbin
	1988	Shield of the Royal Arms representing the United Kingdom. **Edge Inscription:** DECUS ET TUTAMEN **Designed by:** Derek Gorringe
	1983 1993 1998 2003 2008	Royal Arms representing the United Kingdom **Edge Inscription:** DECUS ET TUTAMEN **Designed by:** Eric Sewell
	1984 1989	Thistle and royal diadem representing Scotland. **Edge Inscription:** NEMO ME IMPUNE LACESSIT **Designed by:** Leslie Durbin
	1985 1990	Leek and royal diadem representing Wales. **Edge Inscription:** PLEIDIOL WYF I'M GWLAD **Designed by:** Leslie Durbin

Disturb section 2

Q25

This question lets you record and manage how long a participant spends on this page. This question will not be displayed to the participant.

10

1997
2002

Three Lions passant guardant representing England.

Edge Inscription:
DECUS ET TUTAMEN

Designed by:
Norman Sillman

2004

A representation of the Forth Railway Bridge inside a border of railway tracks.

Edge Detail:
Decorative pattern symbolising bridges and pathways

Designed by:
Edwina Ellis

2005

A representation of the Menai Bridge inside a border of railings and stanchions.

Edge Detail:
Decorative pattern symbolising bridges and pathways

Designed by:
Edwina Ellis

1994

Lion Rampant representing Scotland.
Edge Inscription:
NEMO ME IMPUNE LACESSIT

Designed by:
Norman Sillman

1995
2000

Dragon passant representing Wales designed by Norman Sillman

Edge Inscription:
PLEIDIOL WYF I'M GWLAD

Designed by:
Norman Sillman

1996
2001

A Celtic Cross with a Pimpernel Flower in the centre surrounded by an ancient Torc representing Northern Ireland.

Edge Inscription:
DECUS ET TUTAMEN

Designed by:
Norman Sillman

Disturb section 3

This question lets you record and manage how long a participant spends on this page. This question will not be displayed to the participant.

10

2014

A depiction of the floral emblem of Scotland

Edge Inscription:
NEMO ME IMPUNE LACESSIT

Designed by:
Timothy Noad

2015

A depiction of The Royal Arms

Edge Inscription:
DECUS ET TUTAMEN

Designed by:
Timothy Noad

2016

The Last Round Pound

Designed by:
Gregory Cameron

View products that feature this coin

Question Block

Q1: Recall the 1 pound in the picture. What is its shape?

A. Round shape

B. 12-sides shape

C. 7-sides shape

D. 11-sides shape

Q2: Recall the 1 pound in the picture. What is its thickness?

A. 2.8mm

B. 2.0mm

C. 2.35mm

D. 2.30mm

Q3: Recall the 1 pound in the picture. What is its maximum diameter?

A. 23.43mm

B. 20.00mm

C. 25.55mm

D. 25.00 mm

Q4. Recall the 1 pound in the picture. What is its colour?

A. Gold

B. Silver

C. Copper

D. Gold and Silver

E. Copper and Silver

Q5. Recall the 1 pound in the picture. Which of the following flowers does it own? （Multiple Answer）

A. Cherry blossoms

B. League

C. Thistle

D. Shamrock

E. Rose

F. Bluebell

G. Tulip

Q6. Recall the 1 pound in the picture. Do you know which company made it?

(If you know, please write down the name.)

D. Yes_________
E. Maybe
F. No

Q7: Recall the 1 pound in the picture. What version of the coin portrait is it?

A. the 3rd

B. the 4th

C. the 5th

D. the 6th

Q8. Recall the 1 pound in the picture. Do you know which technology was used to cut it?

A. Using cutting-edge technology

B. Using Laser cutting edge technology

C. Ultrasonic lace trimming

Personal questions

Q1: What is your gender?

Q2: What is your age range?

Q3: Which is your ethnic group?

Q4: How long have you lived in the UK?

Appendix G Questionnaire for Cyclical Multi-sensory Memory Experiment 3: Research from short-term memory to long-term memory (Video, audio, and objects as media)

Memory test 3 (First time complete）

Q1: Recall the 1 pound in the picture. What is its shape?

E. Round shape

F. 12-sides shape

G. 7-sides shape

H. 11-sides shape

Q2: Recall the 1 pound in the picture. What is its thickness?

E. 2.8mm

F. 2.0mm

G. 2.35mm

H. 2.30mm

Q3: Recall the 1 pound in the picture. What is its maximum diameter?

E. 23.43mm

F. 20.00mm

G. 25.55mm

H. 25.00 mm

Q4. Recall the 1 pound in the picture. What is its colour?

F. Gold

G. Silver

H. Copper

I. Gold and Silver

J. Copper and Silver

Q5. Recall the 1 pound in the picture. Which of the following flowers does it own?（Multiple Answer）

H. Cherry blossoms

I. League

J. Thistle

K. Shamrock

L. Rose

M. Bluebell

N. Tulip

Q6. Recall the 1 pound in the picture. Do you know which company made it?

(If you know, please write down the name.)

G. Yes_________
H. Maybe
I. No

Q7: Recall the 1 pound in the picture. What version of the coin portrait is it?

E. the 3rd

F. the 4th

G. the 5th

H. the 6th

Q8. Recall the 1 pound in the picture. Do you know which technology was used to cut it?

D. Using cutting-edge technology

E. Using Laser cutting edge technology

F. Ultrasonic lace trimming

Personal questions

Q1: What is your gender?

Q2: What is your age range?

Q3: Which is your ethnic group?

Q4: How long have you lived in the UK?

Memory test 3 (two weeks later)

Block 1: Based on the video player two weeks ago, recall the characteristics of £1, and then answer the following questions. （Don't try to find the coin to view）

Default Question Block

Have you observed/touched £1 after doing the test?

A. Yes

B. No

C. No impression

Other questions and format are the same as in Questionnaire 3 Memory test 3 (First time complete)

Appendix H Introduction to the £1-coin, Video Audiovisual Material

Web address: URL: https://www.youtube.com/watch?v=ypJYTbOy4No&t=4s