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When Exhibitions Become Experiences

the nARration of Augmented Space inside a science museum

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To the memory of my grandma

Abstract

Nowadays, ever-evolving spatial informatics and digitalised technological possibilities are rewriting the traditional museology by changing the previous exhibition pattern from collection-centred to experience-centred, and further allowing physical space to be transferred into a mixed-reality environment. Those ubiquitous digital formats also allow museum curators and exhibition designers to envision and develop an engaging narrative for museum exhibitions with a brand new vision, where computational elements such as augmented reality (AR) systems and I/O (Input/output) devices are seamlessly embedded within the fabric of physical spaces, and that is included those interactive exhibits that populate these augmented spaces. This PhD thesis is focused on the concept of 'Augmented Space' and its design sensitivities, not only by combining physical space and all kinds of AR technologies as the one, but also exploring this new spatial format in a broader sociological context of augmented interaction that flows between digital and physical layers inside museums. Throughout the article, augmentation is reconceptualised as an idea / concept and cultural / aesthetic practice rather than as the pure technology.

In order to characterise this in greater depth, the first part of the thesis provides an analytical overview of the significant literature published on the topic of Museum Studies; AR technologies; Museum Learning and Interactive Experience. The **Literature Review** combines the key conceptual, methodological and practical issues, which summarises together as aiming to give a fairly comprehensive theoretical background. And hopefully helps designers and researchers dealing with the full range of issues of novel AR systems present within the original physical form. Based on the theoretical framework generates from the first part of the thesis, the second part adopts **Descriptive Research**, which holds an important place in the study of human interaction and learning. It begins with analysing narrative design features of two science museums in the UK - Magna Science Adventure Centre (generally abbreviated as MAGNA) and Thinktank Birmingham Science Museum (generally abbreviated as THINKTANK). Analytical studies were intensively focused on visitors' experience studies and featured augmented space analysis. All those reflections based on descriptive studies led to the definition of a series of corresponding "design sensitivities" to be used for augmented space planning and future exhibition making. The author adopts **Experiential**

Research in the third part of this thesis, “design sensitivities” which generated from case studies were carefully embedded into an ongoing project - Hong Kong Space Museum (generally abbreviated as HKsM). Contemporary issues and practical approaches of creating scientific exhibition and narrating augmented space within the museum industry were described in detail in this part.

This thesis articulates the notion of augmented space, highlights different dimensions of augmented space that visitors perceived from science exhibition settings, and further generates theoretical convergences; technical implications and practical reflections. It aims at bring novelty from spatial, technological and experiential perspectives to the co-productive exhibition-making. The thesis finally points out the shortcomings and limitation of this PhD research and provides advice and directions for future works.

Keywords: Augmented Space; AR Technologies; Science Exhibition; Space Narration; Design Sensitivities; Project-based Research

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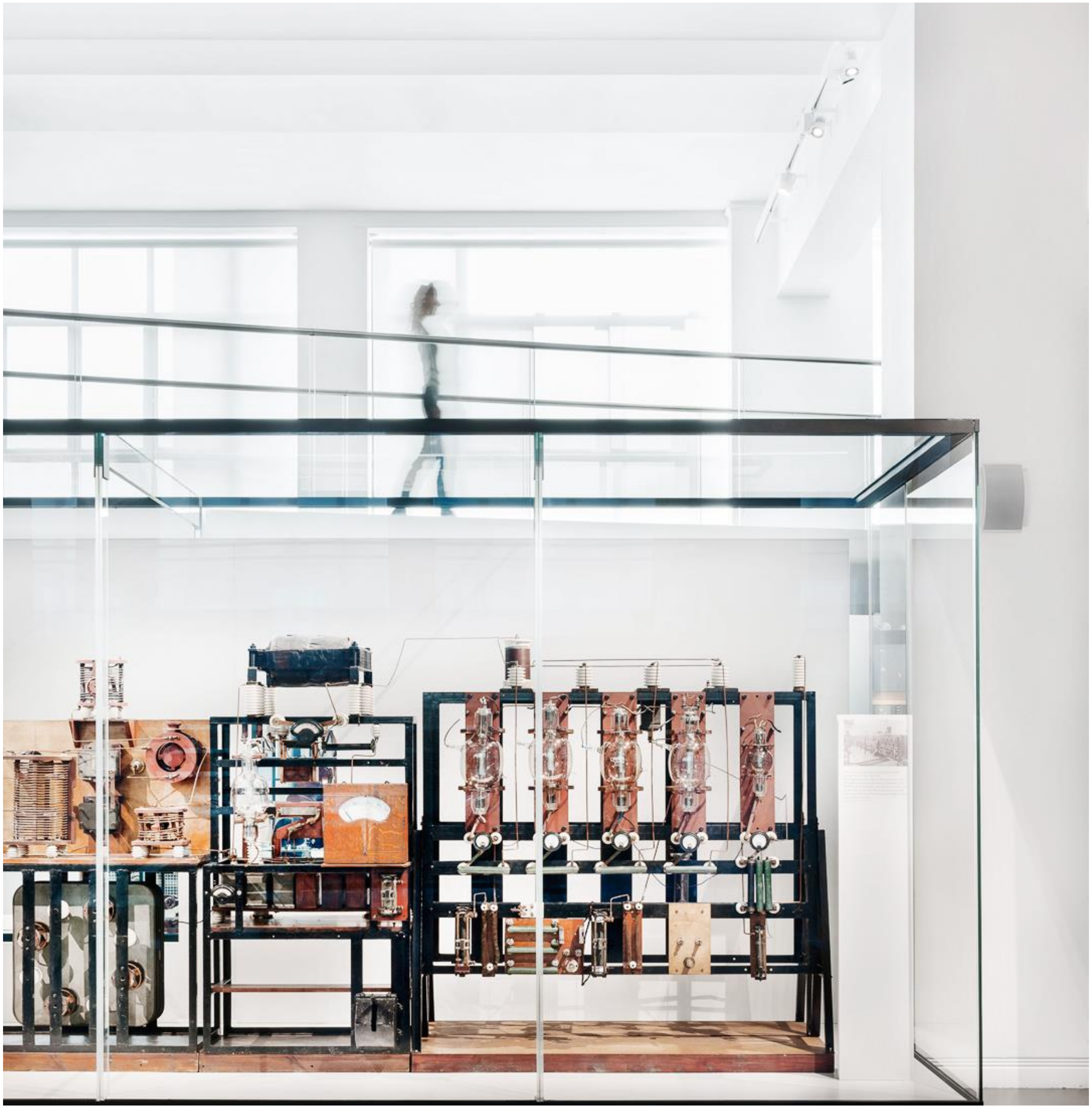


Chapter 1.

Introduction

Figure: Meredith, Andrew. (2015) Photograph. Information Age Gallery inside Science Museum.

Chapter1. Introduction

1.1 Research Background

1.1.1 Museums in the technological landscape

Museums are at a point of transition. It's more like a 'technology-driven mutation' in the evolution of cultural heritage institutions, redefining the sector and blur institutional boundaries (Knell, 2003). At the same time, a brand new musicological impulse between the physical and digital is now in full bloom, and seems to be the first step in articulating what hybridity means from museum communication perspective. The contributions from Mogens Jacobsen, Linnea Jacobsen and Lotte Philipsen discuss how the new museum environment include visitors in constructions of a virtual (digital) layer that in some way or other stand in intellectual relation to the physical setting. The new relations that seamless and hybrid technologies open for include establishing different conceptions of museum communication, and integrating all the visitors, not as recipients, but as co-creators.

On the other hand, digital technologies have long been associated with the promise of providing valuable and unique new opportunities to enhance and support participatory and learning experiences in museums, science centres, zoos and aquariums (Drotner & Schrøder 2013; Giaccardi 2012; Simone 2010; Tallon & Walker 2008). And there has been an increasing attention to the understanding of the physical context of user's experience of interactive systems, within the fields of HCI (Human Computer Interaction), CSCW (Computer Supported Cooperative Work) and Interaction Design for museums. The evolution and expansion of enhanced technologies show that the discipline's focus has shifted from the interaction episodes occurring between an individual user and the computer system like HCI, to a more complex domain of the user interaction within rich physical, culture and social environment.

However, in term of user and activity analysis, the notion of interaction is usually confined to these two subjects: the human user and the computer. From this assumption, the idea of 'user modelling' has been introduced into HCI, as a set of data that attempts to describe the features of a supposed user is incorporated into a system inside the built environment, in order to make it aware of the features and preferences of the visitors and anticipate their interactions (Rich, 1989). They will be able to adapt dynamically their behaviours based on the context changes of users. This ability consists in perceiving the environment and detecting its contextual parameters. On the basis of these factors, the system can react to the environment variations and responds to different user's requirements (Küpper and Kobsa, 1999). This was challenged as limited and incomplete by subsequent research in the area, and other elements of analysis have been gradually incorporated in the process of understanding interaction design with emerging technologies. Specifically, the social context of interaction is the major issue introduced by CSCW, and especially the dimensions of 'collaboration' like group use of technology, and the dimension of social interaction around the use of collaborative systems (Bannon, 1992). This perspective stresses the importance of focusing on the human use of technology, rather than on the technology itself (Bannon, 1991). It also provided useful critiques of the theoretical orientation of HCI, proposing a new vision of the interaction between humans and computer systems that overcome the limits of a cognitivistic approach. However, the physical context of interaction is still a relatively neglected aspect of interaction.

By using ubiquitous and pervasive technologies nowadays, enhanced technologies can be distributed through the defined space or embedded into its spatial elements. For the effective design progress, spatial features need to be studied and included in the development process. Without the proper analysis and understanding of these technological features within the space, the result of an interactive system will not be effective as planned, and the purpose and characteristics of the augmented space can be easily misunderstood, misused, or completely ignored.

With the new technologies, the old museum experience will be adapted totally, because spatial information has become ubiquitous as place-based information inside the museum; navigation systems and instant mapping have been integrated with the tools that museum visitors use. The interface and system design of these digital tools are dramatically affecting the way visitors obtain, spread and interact with the spatial information inside the new interactive museum environment. Although some work has been done on enhancing the design and development of purely virtual environments (like 3D virtual museums), particularly looking at the way users experience them and collaboratively interact through them (Benford et al., 1997), very few theoretical reflections have occurred regarding the technological augmentation of actual physical locations and concepts or ideas of defining augmented space like that. Similarly, reflections on the nature and features of space have been proposed in order to inform the design of virtual spaces, rarely of physical ones.

1.1.2 New interaction for museum communication and learning opportunities

Education will always be a key role for any kind of museum and it drives their mission through every activity. As Eliean Hooper-Greenhill mentioned in her book - A museum educator's perspective, it mentioned an important task for a museum always is to plan the learning opportunities of exhibitions and displays and demonstrate collections of artefacts/exhibits as the new educational value (Hooper-Greenhill, 1995). Technologically-enhanced methods allow the museum to imagine of creating immersive experiences and narratives in unprecedented ways around the original physical space. And the original museum space is gradually being replaced by participatory technologies which made a great effort on presenting information, communicating with audiences, and converting technology and scientific knowledge to their visitors in innovative ways.

Museums also recognise the importance of understanding how their visitors learn and how learning can be encouraged inside the museum through the new augmented space and its spatial narrative. As Hooper-Greenhill pointed out four years later in 1999, the development of effective exhibitions 'needs to take account of both what people want to know, would be interested in, and how they can come to know it – how they learn' (Hooper-Greenhill, 1999). In another word, a good exhibition does not only provide two or three-dimensional interactive artefacts, it also comprises educational material and knowledge - which are concerned with a collection of digital (or interactive) artefacts for the meaning-making process of visitors through a well-balanced structure of narratives and ideas. From the author's perspective, that is the core of constructing innovative narration for a scientific exhibition.

Nowadays, augmented technologies in museum enforce the notion of interaction and communication gradually, which alters the traditional perspectives and requires much more attention in the context of research on learning with digital media in the museum. In this regard, Wertsch (2002) outlines the perspective on how mediation with digitally-cultural tools constrains as well as empowers human action, and he also discusses how our emphasis is often on the empowerments rather on the constraints. It is important to look at how these tools shape our action in an inherently limiting way, even the digital media and augmented technologies are a new phenomenon and hot topic in the profession of museum communications, issues on constraints as well as empowerments need to be investigated.

John Seely Brown (2000) has once discussed how we can imagine a future of learning ecologies where learning, work and play fold together and he argues that learning becomes ubiquitous (Brown, 2000). For John Brown, the future platform is more like an embodied media that honours several forms of intelligences, abstract, text, visual, musical, social and kinaesthetic. It further facilitates the ability to construct a learning environment where young people have the opportunity to engage in learning on their own optimal way (Brown, 2000). The skills and literacy of information navigation are in Brown's understanding of media literacy, which argues for a move beyond text and image: the skill of being one's own librarian. In the educational context, this will lead to a dominance of discovery-based learning. Based on this understanding, we could say that, as a constructive object for studying and developing a learning environment, museum nowadays enables and facilitates digital media's position in today's theories of learning.

By playing a significant role as educational institutions, museums interpret the versatility of meanings of their collections for communication of knowledge. Most visitors in the museum appreciate it as a place of leisure which enriches their experience and allows them to enjoy a social occasion without particular learning goals, as so called 'leisure-learning' (Hooper-Greenhill, 1999). The findings from primary literature have also suggested that since museums normally provide a free-choice learning experience, the motivation is also key in effective learning; experiences should be stimulating, enjoyable, relevant and appropriate for the visitor' (Hawkey, 2004). Roy Hawkey has also surveyed the current scene critically in the NESTA (the National Endowment for Science, Technology and the Arts) Futurelab Research report, as a former Head of Education in a national museum, he reckoned, 'if museums have embraced new technologies, the multidimensional and truly multimedia nature invests them with significant advantages over other learning providers, both formal and informal' (Hawkey, 2004), as it is illustrated as **Figure 1.1.2-1.**

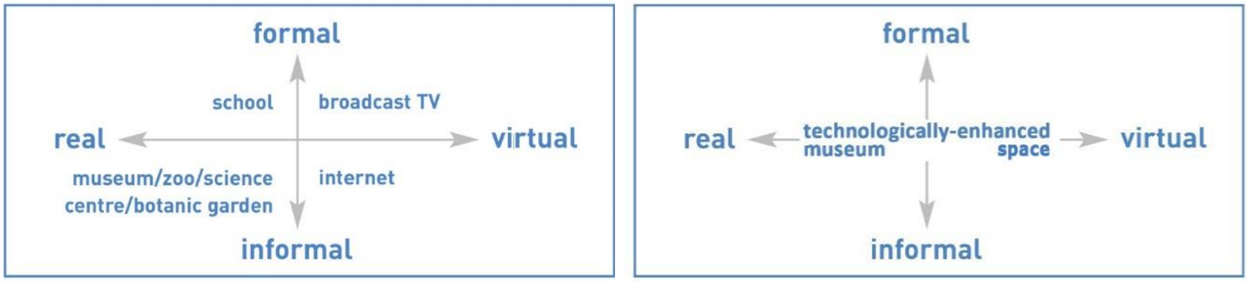


Fig. 1.1.2-1: Technologically-enhanced Museum Space - Persistent dichotomies or blurring the boundaries?

Source: Hawkey, 2004

Today's highly-digital strategies to enrich education and interpretation should be a part of the museum's mission, adapted to its goals and means. Participation in learning networks and collaborations between museums and other social institutions are opening up new opportunities to reach out to and engage with larger audiences, as well as to increase the visibility of their multimedia digital assets for educational purposes. The new technologically-enhanced museum space becomes an instrumental part of the learning ecosystem and bridges the gap between formal and informal learning; real and virtual setting. On the other hand, museums should develop clear frameworks to shape a coherent and sustainable pedagogy for digital strategies and augmented space.

As the author has noticed on numerous occasions, very few theoretical and practical reflections have occurred regarding the design methodologies for comprising an educational material or knowledge with digital augmentation[1] inside museums, for constructing a truly meaning-making process through well-defined digital narratives. This PhD thesis intends to find digitally-enhanced (augmented) strategies for museum education, which acts as well-articulated mission and vision, to further strengthen the value of

1 The enhancement of virtual presence through the use of digital content.

scientific exhibition by providing inspiring and engaging lifelong learning opportunities for all kinds of museum visitors.

1.1.3 New senses of place: augmented space

Throughout recent decades, with more and more digitally-advanced artefacts have been adopted by museums with a wider range of social and natural properties, exhibition development in museums also become a relatively complex activity, which is expanding beyond the design discipline (Dean, 1994). In particular, the museum provides a public service and communicates its collections and associated information using a variety of embedding technologies (Miles et al., 1982; Belcher, 1991; Fahy, 1999; Hsi & Fait, 2005; Dindler et al., 2005; Hornecker & Stifter, 2006). Emerges from the review of literature that the interest in physical space seemed to remain in the background for several years, as much work had been done regarding virtual spaces (e.g. 2D or 3D digital representations of physical spaces), or even "space-less" (e.g. not organised on the digital reproduction of actual spaces) environments. Some in-depth reflections and detailed conceptual approaches have been proposed to tackle the design problems faced when re-creating environments digitally, but this hasn't happened to the same extent for the design of actual physical environments. In fact, physical space seems to re-appear as an object of study more recently, in conjunction with the establishment of a community of interest on ubiquitous technologies, in other words, when the technical possibilities of augmenting the actual physical spaces we inhabit became apparent.

The focus of this PhD thesis is specifically based on augmented space where AR systems are physically embedded within the built environment, offering possibilities for museum visitors to interact with tangible artefacts and surrounding physical environment. At the same time, their visitors are able to get access with unlimited information by triggering different digital content types or various reactive behaviours. The author argues that understanding fundamental characteristics and potential manifestations of augmented space, particularly according to the existing AR literature, can be an essential tool to help spatial designers, creative practitioners and museum experts to learn more and deeper for the 'golden triangle' between visitors, exhibits/exhibition and experience.

In parallel with the above identifications and discussions, the literature research of this thesis aims to propose a thorough and comprehensive framework which illustrating all the possible connections between above golden triangle with architectural space (physical), augmentation tools (digital), exhibition narration and museum learning (as shown below).

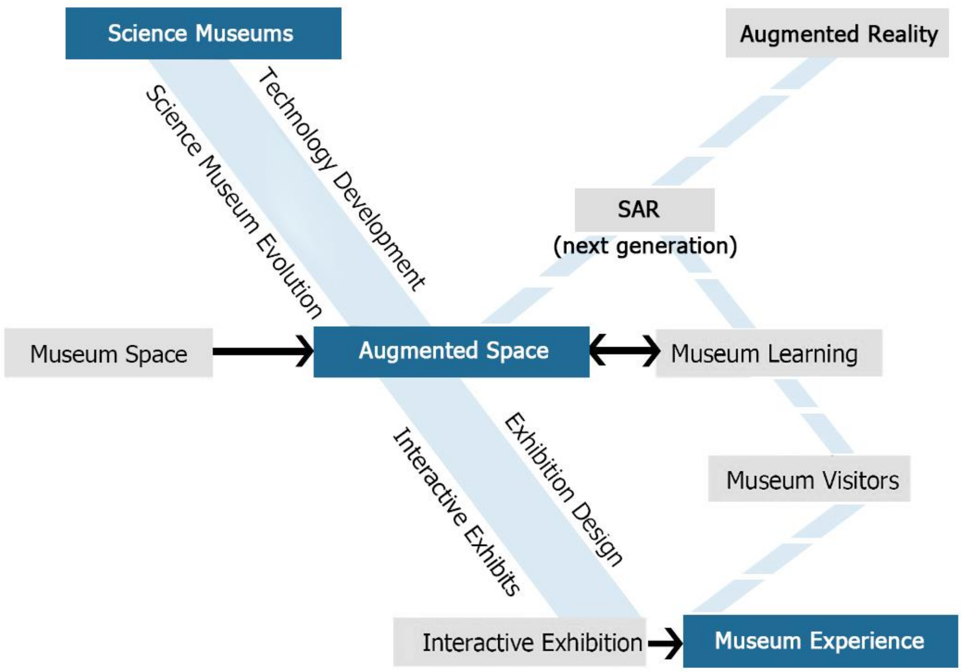


Fig. 1.1.3-1: The proposed knowledge framework of augmented museum space for the PhD study.

In summary, the contribution of this study is three-fold in terms of theory, method and practice. It will first try to define augmented space through a review of contemporary literature and understandings; then, expands in proposing a new set of concerns for narrating augmented space within museum practice. Those reflections from theoretical and practical approaches would eventually contribute to the development of the augmented space inside the science museum for interactive narration and immersive storytelling, enabling museum visitors to interact with the enhanced museum environment seamlessly, naturally and effectively. This thesis subsequently helps museum curators in designing more adaptive, engaging, exciting and entertaining learning experience with latest implants and digital augmentation.

1.2 Research Aims & Objectives

With ubiquitous technologies becoming increasingly reliable and widespread, we are now dealing with fully interactive physical spaces and tangible elements as interfaces for accessing the digital domain and fully-fledged outreach platforms. When an AR system is introduced into an existing environment, it clearly changes the spatial narrative based on pure physical layer, as well as the way people perceive the total environment. Moreover, it allows users to use it and modify it for their purposes. This also changes people's attitudes, values and feelings which were associated to that specific locale. As briefly mentioned above, this thesis is particularly concerned with the understanding of those ubiquitous novel digital-enhanced systems inside the museum environment, which is augmenting the original physical layer with novel possibilities for a highly-interactive narrative form.

The author believes it is crucial for curators and designers to analyse and understand the process of space augmentation for exhibition narrative, in order to further design the exhibition space and evaluate the technology in a thorough and effective way. In other words, museum designers need to focus on the connections between architectural (physical) spaces, augmentation (digital) tools for creating innovative exhibition narratives. In this case, the ultimate goal of this research is to find out those comprehensive approaches to spatial augmentations and digitally-enhanced methods which helps designers to cope with the complexities of multi-disciplinary augmented space design and interactive exhibition narration.

In particular, **Research Aims** of this PhD thesis include -

1. To identify the impact of technology development on the evolution of the scientific exhibition.
2. To define augmented space based on AR literature.
3. To get a specific conceptual and methodical articulation of Spatial AR within the process of learning.
4. To connect museum experience, interactive exhibits and design development altogether.
5. To find out efficient 'design sensitivities' for augmented space-making, which copes well with the complexities of interaction exhibition narrative.

6. To understand the relationships between physical spaces, digital technologies and the narration on the basis of interactive exhibiting, looking for clues for the appropriate use of the dynamics of architectural space and digital augmentation to develop engaging experience in practice.

In parallel with these research aims, **Research Objectives** include -

1. To review the relevant literature about scientific museums focusing on historical and cultural aspects, digital augmentations, learning theories and the effectiveness of their spatial communication.
2. To identify the potential relationship between museum visitors and the museum experience under the digital augmentation by field observations.
3. To identify those pedagogical benefits of augmenting space from current scientific galleries.
4. To examine the existing comparable augmented space and exhibition narratives with a special focus on physical space and digital technologies.
5. To validate 'design sensitives' generated from case studies via the design-based research.
6. To propose a reference model for developing effective and innovative museum exhibition and contextual learning environments in the museum practice.

1.3 Research Questions

Derived from the research problems and the before mentioned research aims & objectives the following main research question is formulated:

How to establish a new paradigm for understanding augmented space inside science museums, together with comprehensive spatial and digital enhanced methods to develop engaging experience and effective learning in practice?

In order to answer the main question, the following sub research questions with different methods conducted consecutively:

Sub Research Questions		Research Conducted
RQ1	*How did scientific museums evolve from historical representations into immersive environments using augmented reality (AR) systems?*	Literature review Document study
RQ2	*How to re-conceptualise the world 'augmented space' from the relating AR theories?*	Literature review Document study
RQ3	*What are the pedagogical benefits of augmenting space for museum learning?*	Literature review Document study
RQ4	*What are the latest technological enablers for spatial perception, cognition and interaction for the museum environment?*	Literature review Document study
RQ5	*How to connect interactive exhibits with museum experience, to better understand and meet their visitors' multiple needs and expectations.*	Literature review Case studies Cross-case analysis
RQ6	*Are there particular concepts and perspectives that can support the narration on the basis of interactive exhibiting, based on the dynamics of physical space and digital tools to develop engaging experience and effective learning.*	Literature review Case studies Cross-case analysis
RQ7	*How can those design sensitivities influence practical aspects of scientific exhibition design?*	Literature review Design-based Research (DBR) Discussion

Fig. 1.3-1: Proposed sub research questions with different conducting methods in this PhD research.

1.4 Research Outline

In general, this thesis can be divided into three parts: 1) Theoretical Framework; 2) Descriptive Research and 3) Experiential Research, each part encompasses a number of chapters and sub-headings. The detailed content of each chapter is outlined as follows:

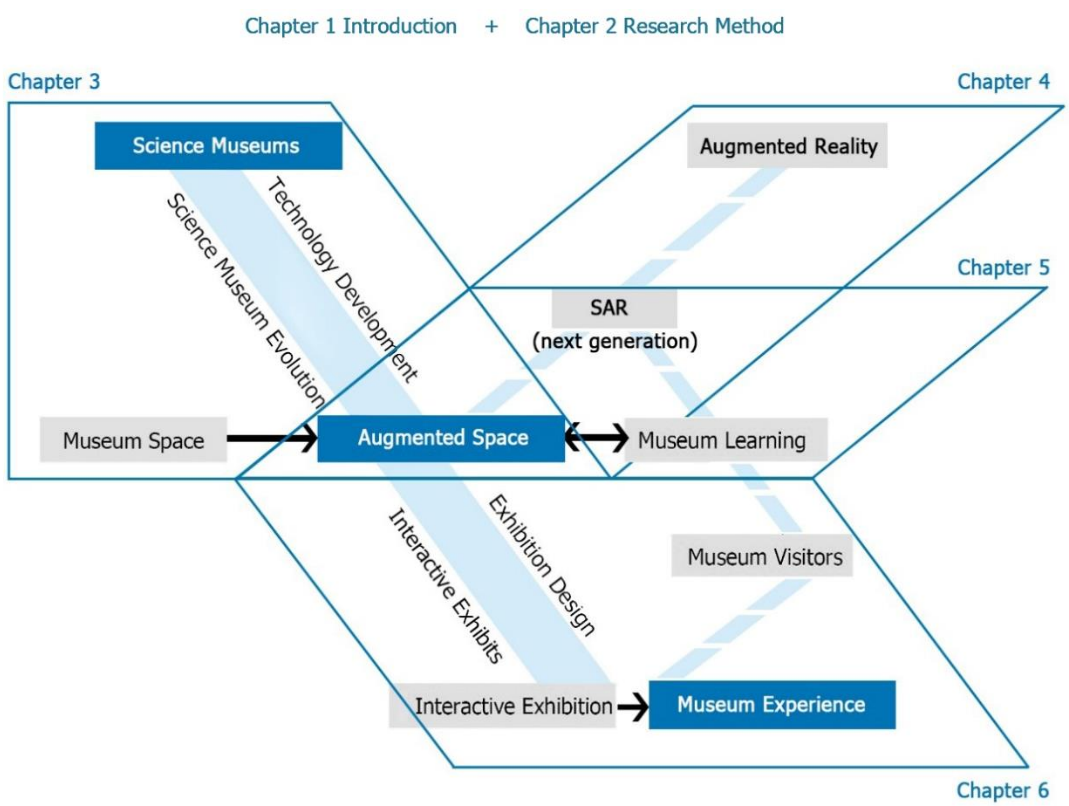
Chapter 1 describes the research motivation, the statement of the research problems, aims and objectives of the research, as well as formulating detailed research questions, and proposing the overall structure of this thesis. **Chapter 2** deals with research design and methodology, describing the two-phase, sequential mixed-method studies (descriptive and experimental researches) presented in this thesis.

Seeking to outline previous research, mainly from the literature review, the first part of this research set the foundation for the PhD study, and it consists of four chapters - **Chapter 3** examines how 21st century museum exhibits evolved from historical/aesthetic representations into interactive and immersive learning objects using digital technologies. This chapter starts to introduce augmented reality (AR) at a later stage, since digitally augmentation and embodied interactions change the original spatial form and act as a new genre of communication for science museums. And in **Chapter 4**, the author starts to review both theoretical and empirical work within the AR literature to further define the term 'augmented space' for this PhD research. After that, a review moves to augmented space for museum making, as **Chapter 5** investigates learning perspectives of a museum environment, and illustrates the difference between interpretive and constructivism learning from guilds to augmented space, and **Chapter 6** tries to link museum experience with the actual interactive exhibition design in the museum practice, which also bridges the gap between theories and practices in augmented space design.

Chapter 7 starts the second part of this PhD thesis - case studies. It focuses on analysing two existing augmented space designs and their spatial narrations within two distinguished museum cases in the UK - Magna Science Adventure Centre (MAGNA), and Thinktank Birmingham Science Museum (THINKTANK). This chapter also discusses different conceptualisations of each featured space that have emerged to support the conceptual design of such systems, as well as the feedback from museum visitors. Reflections on these interaction episodes inside these augmented spaces further leads to the definition of a series of corresponding "design sensitivities" for informing the design of the scientific exhibition.

On the third part of this thesis, "design sensitivities" from case studies were embedded into the Hall of the Cosmos in the Hong Kong Space Museum (HKsM) project. **Chapter 8** describes one practical application of embedding the augmented space for an interactive (scientific) exhibition in the museum practice. Since the author has engaged in this project for nearly two years during her PhD, this research project became a great opportunity to combine theoretical reflections and field research with practice in the real world, transferring research knowledge into the action and discusses how it can be used for developing a useful model of the featured augmented space-making process and influencing practical aspects of scientific exhibition design.

The last chapter (**Chapter 9**) draws overall conclusions and summarises the main research findings, achievements and contributions to knowledge, followed by recommendations for further research. The structure of this PhD research is presented in **Figure 1.4**.



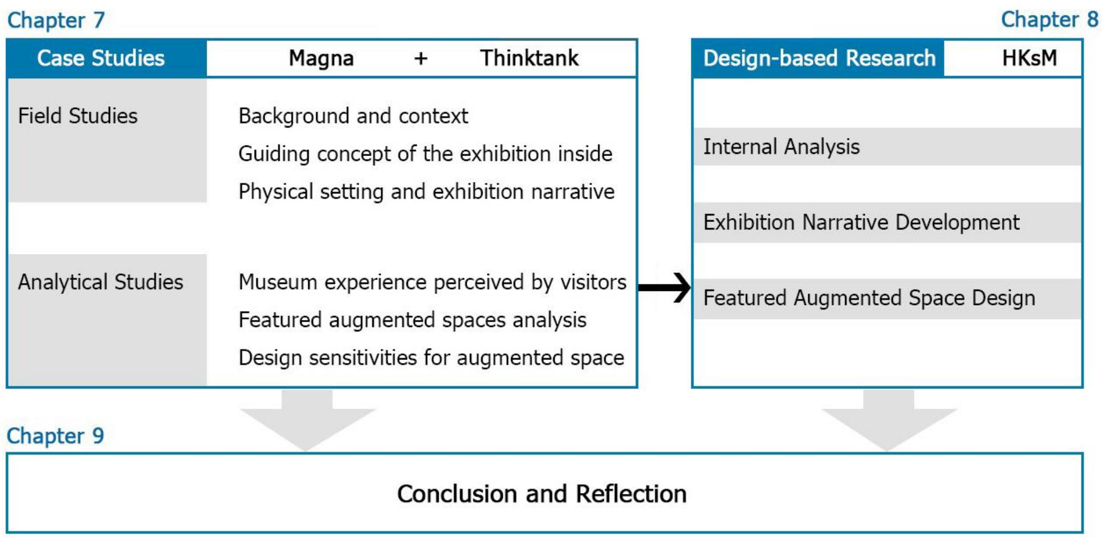
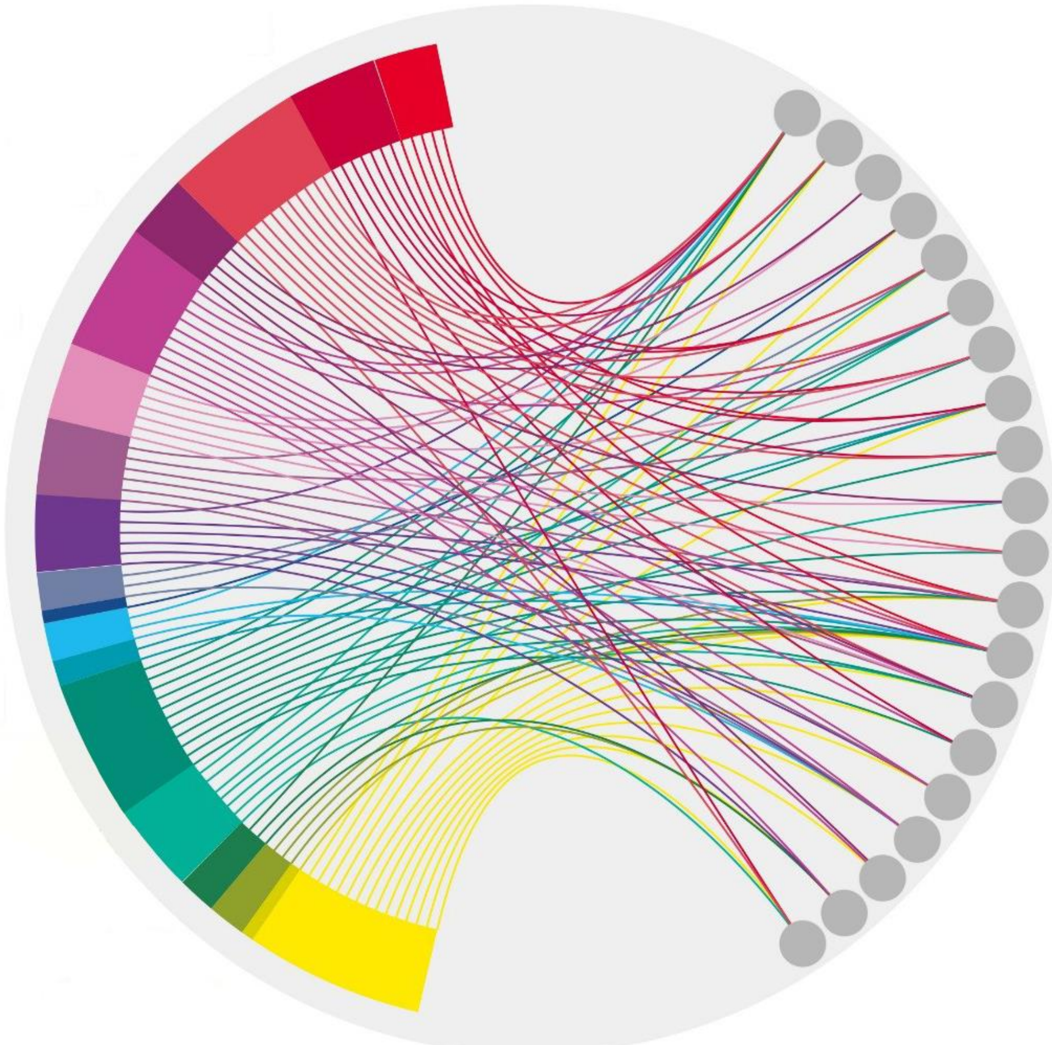


Fig. 1.4: The structure of this PhD thesis.

1.5 Research Scope

The researcher's familiarity with the content of the scientific exhibition and augmented space development are mainly through previous studies during her industrial experience as an exhibition designer. Given the research focus on the influence of design elements on the conveyance of the indented information of an exhibition with AR technologies, the scope of this study is limited to the relationship between curatorial interpretation and final representation of the featured augmented space in the gallery, which flows between digital and physical layers of the specific exhibition. Audience interpretation of the intended messages is thus beyond the scope of the intended investigation. Another reason is because the Design-based Research (RBR) Project - Hong Kong Space Museum is still under construction at moment, and according to the development progress, the renewed galleries will firstly be opened for application for visits from schools at the end of 2017 for exhibit trial run and evaluation purpose. The exhibition halls are expected to be re-opened to the public at the end of March 2018. In consequence, it is impossible to get Whilst-use Evaluation and Post-use Evaluation from the museum visitors on site. However, this DBR still propose a good reference for interconnecting the early curatorial interpretation and the final experiential representation for the museum practice.



Chapter 2.

Research Methods

Figure: Russell, Vincent. (2017). Illustration. Narrative Project.

Chapter 2. Research Methods

2.1 Chapter Overview

The function of research design is to develop a specific research methodology into an explicit, systematic and well-structured framework for undertaking research. The research methodology underlying this thesis initially took two philosophical streams under empirical research methods (**Figure 2.1-1**), namely, the reflective case study under the descriptive research, which provides an in-depth review and closer approach to the nature of augmented space design inside existing science museum environment. As well as the design-based experiment under the experimental research, which provides a more systematic approach to the learning-by-doing nature of augmented space-making within the scientific exhibition design process. Blending the two perspectives was considered the appropriated outline to understanding and utilising design sensitivities for augmented space in real life design practice.

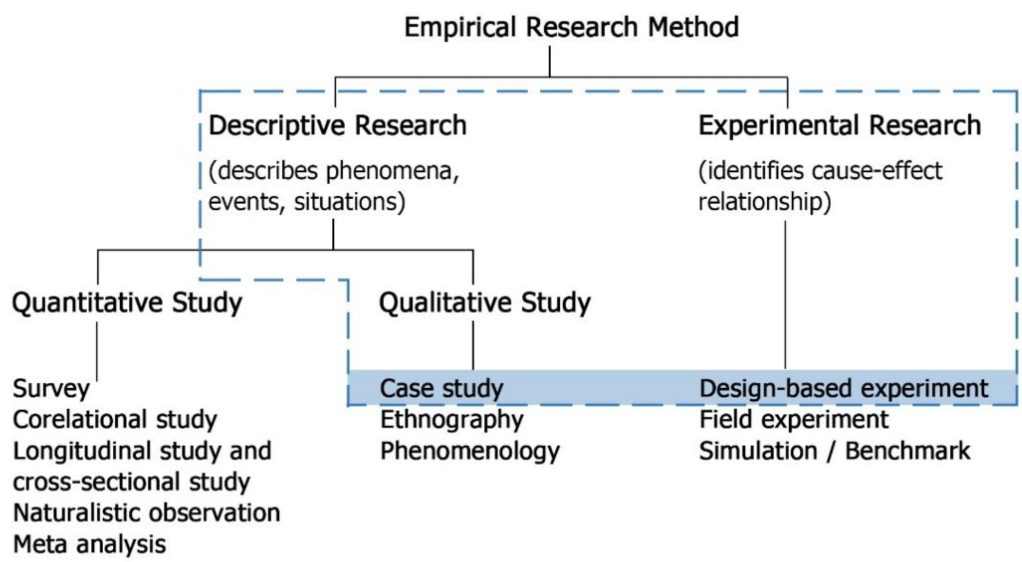


Fig. 2.1-1 This thesis adopted both descriptive research and experimental research

Source: Empirical research methods for software engineering, prepared by Dr. Sarfraz Nawaz Brohi & Dr. Mervat Adib Bamiah

2.2 Qualitative Research

In general, Quantitative methods are defined as techniques that enable a researcher to generalise findings from a sample of response from a large population (Creswell, 1994). Quantitative methods research uses a precise measurement that presents a systemic view of phenomena by specifying relationships among variables.

Additionally, Qualitative methods provide overviews and research background, while Qualitative research has been associated over the years with the proponents of the contextual approach (Silverman, 2002, 2005 & 2009), arguing that qualitative approaches offer access to valuable type of data and a deeper and richer understanding of human behaviour - with Qualitative research, a number of persons, places and events are involved. In particular, literature study is heavily used in a manner consistent with the methodological assumptions of qualitative research, and it should be used inductively so that it does not direct the questions asked by researchers. As Law described in his PhD thesis in 1996:" Qualitative methods can serve to reveal and understand the background to many phenomena about which little is known. They can generate new and fresh insights relating to issues about which there is already considerable knowledge. Qualitative methods can also reveal intricate details of phenomena that are difficult to realise with quantitative methods (Law, 1996).

In conclusion, there are three characteristics of the qualitative study that researchers have to consider whilst conducting research project: 1) Concerning with the personal, face-to-face, and immediate; 2) Focusing on understanding given social settings, not necessarily making predictions about those setting; 3) Looking at the large picture, the whole picture, and begins with a search for understanding of the whole. (Janesick, 2000)

For this PhD research, the main elements of qualitative methods are of three types:

1) **Literature survey** - it frames research problems and places them in separated sections. The literature review from **Chapter 3** to **Chapter 6** helps to answer the research questions that the author has raised in the introduction, which can be used for comparing with the later findings from the case study and design-based research. The sources of this section are paper publications (which

includes journal articles, books), reports, records or digital publication. The literature research also contributes to the preliminary survey of case studies.

2) **Case study** - as an ideal method when a holistic, in-depth investigation is needed, case studies are designed in this thesis to bring out details from two museum cases in the UK by using multiple sources of data. There are six different sources that can be identified for conducting the phase of case study research, which are documentation, archival records, interview, questionnaires and direct observation. And further analytical studies between cases provide researchers with opportunities to analyse data in order to strengthen the research findings and conclusions.

3) **Design-based research** - DBR is typically imagined as a form of Qualitative research, which is mainly because Qualitative research addresses the problem meaning and used in the context of discovery, as opposed to verifying an existing theory. According to the article - Design-Based Research Process: Problems, Phases, and Applications (Easterday et al., 2014), a traditional design and DBR processes consist of 6 iterative phrases in which researchers: 1) focus the problem, 2) understand the problem, 3) define goals, 4) conceive the outline of a solution, 5) build the solution, and 6) test the solution, as shown in **Figure 2.2-1.** The DBR phases in the thesis are not carried out in a linear sequence but rather iteratively in this thesis. Apart from above 6 phrases, it also follows the actual design tasks in relation to the RIBA plan of work (2013), which has often been adopted in the practice.

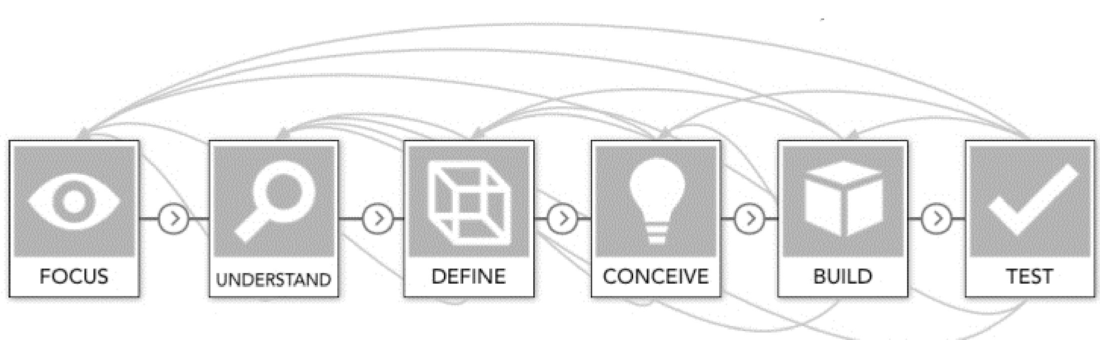


Fig. 2.2-1. The design process consists of 6 iterative phases: focus, understand, define, conceive, build and test

Source: Defined by Matthew W. Easterday, Daniel Rees Lewis and Elizabeth M. Gerber

2.2.1 Literature review and document study

The literature review is an academic exploration of the research objective that provides critical summary and assessment of existing knowledge. In this study, a wide range of literature concerning museum study, museology, augmented reality, augmented space, museum experience and design management was critically studied in order to achieve the following objectives:

1) To obtain an understanding of the philosophy and definition of augmented space and its characteristics for museum functions;
2) To obtain the latest information of embedding augmented reality technologies in museums;
3) To obtain an understanding of spatial augmented reality research and the contribution to learning experience in museum; and
4) To obtain an understanding of the design process for interactive exhibition design with augmented technologies

Based on the literature survey from Chapter 3 to Chapter 6, the author has provided a solid foundation for understanding the relevant aspects of emerging phenomenon and new design paradigm of augmented space in museums with all these objectives above included.

In term of interconnecting the idea of theory and valuable practical insights, information has sought the factors that influence museum visiting and a relevant summary was found in the work of Falk (2009) who proposes an integrated Museum Visitor Experience Model on Chapter 6. According to Falk, the reasons for visitors to go to museums are related to how they experience the visit. Visitors develop such a motivation by balancing what they expect to do during their visiting time with what a museum can offer them. Moreover, aspects that influence the perception of a museum visit can be best described by three contexts in which the visit happens: the personal, physical and socio-cultural contexts. The personal context describes the visitor's personal knowledge and interests and what he/she thinks is essential about museums. The physical contexts consider the design of the museum, its exhibition, the information that is presented but also the basic elements like route, orientation and spatial organisation etc. The socio-cultural context takes into account the contacts the visitor has in the museum, whether it's a group or individual visit, and his/her socio-cultural background.

A literature review concerning interactive exhibits was the subsequent step in this project. Basic information about what an interactive is and how it can be described was sought. The following definition of an interactive was used throughout the rest of the project: an interactive museum exhibit is an object which an individual or groups of individuals can influence (in shape or in content), by involving themselves at the sensory, intellectual and/or emotional level, in order to understand real phenomena and/or learn about museum items.

In the end of Chapter 6, the author also reviews the theoretical and practical models for exhibition design process, these descriptive and prescriptive models are defined as rational and systematic frameworks for increasing the effectiveness of design tasks (Cleland & King, 1993). The descriptive model guides designers and reflects the solution-focused nature of thinking which is subjected to analysis, evaluation, refinement and development (Cross, 1998). And the prescriptive model essentially offers a more algorithmic procedure to show designers how to work more systematically (Cross, 1998 & Newton, 1995). Cross considers that such models emphasise the importance of generating solution concepts, which will be adopted later in the design-based research of this study.

2.2.2 Case studies

Case studies sacrifice breadth of study for depth of study, as it is written in the Good Research Guide: For small-scale social research projects: 'Case studies focus on one instance (or a few instances) of a particular phenomenon with a view to providing an in-depth account of events, relationships, experiences or processes occurring in that particular instance' (Denscomber, 2003). In general, by Chicago sociologists in the early nineteenth century, case study itself is a very detailed investigation of particular phenomena which are often involved with practice. Hakim (1992) points out that it is appropriate to use case studies within research design when the studies involve complex issues. More specifically, the case study emphasises inductive data analysis to provide a fundamental theory of fieldwork in realistic situations.

Preliminary surveys of case studies were conducted first on this stage, through initial literature review and document analysis before the formal field research. This survey is more like a research strategy rather than a method or technique (Robson, 1999). Preliminary surveys set out to address and overcome the difficulty of identifying and developing case studies. The initial basis of this preliminary survey was to investigate design contexts for innovative scientific narration to aid the identification of museum exhibition design phenomena.

The first purpose of preliminary surveys is to provide details of how to select appropriate cases. The survey as outcomes from initial literature review and original documentation analysis will identify the background of science museums and science centres, the characteristics of its physical form and requirements of implying augmented layers. The sources are paper publications (journal articles, books), design reports, tender documents, records or digital publications…which will provide in-depth information about the design intent and design process through curatorial and musicological aspects. Secondly, in order to further understand spatial characteristics and spatial quality of each museum cases, it is necessary to identify criteria in terms of the roles and functions of these exhibition designs, and the finding of preliminary survey guides the author to outline the selection criteria for the cross-case analysis in the end of the chapter, within which issues can be indicated, discovered and studies so that a fairly full understanding of the surveyed cases is possible (Brunelli, 1992).

Analytic techniques were used to examine both fieldwork possibilities and the design quality of those scientific exhibition cases. This survey also involved preliminary analyses of data obtained from various sources. This subsection will concentrate on transforming the qualitative conflicts into a highly-structured case study approach.

As case studies provides a research environment propitious to gathering practical, concrete and context-dependent knowledge essential to gain insight in to casual mechanisms and contextual considerations (Flyvbjerg, 2004). An important step within the design of a case study research is case selection (Verschuren, Verschuren & Doorewaard, 1999; Denzin and Lincoln, 2000), and the author believes that a careful selection of representative and instrumental case studies will provide some reflections for the practical project.

According to the research scope of this PhD, modern scientific museums were firstly identified as the 'general' case-study objects, and 55 science museums and science centres have been primarily selected on the first step, as shown in Appendix 1 – *Museum List*. The selection of the final case-study objects was complied with three rules: Completeness, Representativeness and Comparability. The exhibition galleries inside those science museums and science centres were examined, analysed and synthesised in order to represent the most suitable way of identifying case survey tasks. Two cases were chosen as the ultimate case study objects, which are Air Pavilion in Magna Science Adventure Centre and Futures Gallery in Thinktank, Birmingham Science Museum. Because this research focuses on the modern trends and new museology which have a wide range of subject matter, and both museum and their galleries introduce advanced technologies and interactive exhibition focus on 'Air and Space', as shown in **Figure 2.2.2-1.** Though desk research on each case study, the author got an in-depth exploration and understanding of design aspects of science museum which includes 1) the museum background and context; 2) guiding concepts and design intent; and 3) physical setting and exhibition narrative of the gallery. The sources of this section are tender documents and paper publications (which includes journal articles, books), reports, records or digital publication.

Fig 2.2.2-1: The selection of the final case studies

Source: Photographed by the author, 2015

A range of observation techniques is employed to capture the patterns of visitors' movements through the building and how they use the space. These include a record of movements and activities, snapshot observations and tracking to create a precise picture of spatial movements and visitor counts at room entrances to determine the flow in and out of museum spaces (Psarra, 2009). This observation focuses on the identification of a potential relationship between the visiting patterns and learning activities, the author adopted the total participation, observing visitors' behaviours and identifying the nature of interactions within interactive exhibition environments. The examination of fieldwork from existing exhibition project and museum site observation can also be helpful in understanding the concepts and philosophies of the real event.

The analysis of case studies is one of the least developed aspects of case study methodology. As Yin descripted, "Data analysis consists of examining, categorising, tabulating, or otherwise recombining the evidence to address the initial proposition of a study" (Yin, 1993 & 1994). Data analysis is also a functional way of analysing particular aspects of case studies in more depth (Langrish, 1994). The analysis is heavily shaped by the theoretical framework within which the case study is undertaken (Patton, 1990). The context of such an analysis can be seen to reflect the original form and meaning.

Data analysis and case descriptions can also be developed by qualitative and quantitative methods to carry out the research aims and draw conclusions (Yin, 1994). The quantitative analysis of data deals with data in the form of numbers (Robson, 1999) using summary, scale and quantity calculations. In contrast, qualitative analysis of data only deals with a small number of participants, and illustrates the finding in a descriptive way that intended to reflect the data studied (Newby and Ertmer, 1997). This thesis adopted qualitative method primarily because the researcher's requests to distribute questionnaires in both science museums were refused by department heads, the decision was made to employ informal interviews in analysing case studies altogether with observational study. This decision also helps the author to 'understand and interpret how the various participants in a social setting construct the world around them' (Glesne and Peshkin, 1992; cited in Newby and Ertmer, 1997).

Space syntax analysis also adopted in the case study as a qualitative research method besides observational study and informal interview. Space syntax theory and method published in 1984 by Hillier and Hanson and it highlights the connection between abstract social relations and the physical space through physical space characteristics. The software Depthmap is a Windows-based program for generalised space syntax, it is originally developed from the University College London (UCL), allowing a user to import a 2D layout in drawing exchange format (DXF), and to fill the open spaces within this layout with a grid of points. By using this program, the researcher is allowed to make the visibility graph which representing the visible connections between those point locations. Once the graph has been constructed the user may perform various analyses of the graph" (Turner, 2001). A well-integrated location is shallow (in terms of the number of steps) to all other locations; that is, you do not have to turn often to get from the location to any other in the system. A poorly integrated location is 'deep' with respect to other locations" (Turner, 2004). And all the well-integrated locations will be coloured as red, on the contrary, those poorly integrated ones will be coloured as blue.

This analytical study investigates the gallery space with certain configurational characteristics (i.e. higher integration) are used more frequently and by more people, are recalled more often by these visitors, and are more accurately represented when recalled (Haq & Zimring, 2003). At the same time, spatial cognition research suggests that people perform better on spatial judgment for places that can be accurately schematised and integrated with other spatial knowledge (Tversky, 2003). From these perspectives, researchers believe that there is an area of connection between the features of the physical world (space configuration measured by space syntax) and spatial judgment on the augmented space, which suggests that space syntax measures, such as integration, should predict performance on spatial cognition and human activities inside the gallery space.

2.2.3 Design-based research (DBR)

Drawing on the literature, Wang and Hannafin (2005) proposed five basic characteristics of Design-based Research (DBR): "Pragmatic, Grounded, Interactive, iterative and flexible, Integrative, and Contextual".

First, DBR is pragmatic because its goals are solving current real-world problems by designing and enacting interventions as well as extending theories and refining design principles (Design-Based Research Collective, 2003; Van den Akker & et al., in press). Second, DBR is grounded in both theory and the real-world context (Wang & Hannafin, 2005). Third, DBR is iterative, interactive and flexible in terms of its distinctive research process. Fourth, DBR is integrative because researchers need to integrate a variety of research methods and approaches from both qualitative and quantitative research paradigms, depending on the needs of the research (Wang & Hannafin, 2005). And last but not the least, DBR is contextualised because research results are "connected with both the design process through which results are generated and the setting where the research is conducted" (Wang & Hannafin, 2005).

In the paper 'Socially responsible educational research', Reeves (2000) has nicely summed up what researchers seem to agree on regarding the function of DBR. He lists three critical characteristics of the approach as:

1. Addressing complex problems in real contexts in collaboration with practitioners;
2. Integrating known and hypothetical design principles with technological affordances to render plausible solutions to these complex problems; and
3. Conducting rigorous and reflective inquiry to test and refine innovative learning environments as well as to define new design principles. (Reeves, 2000)

As an exhibition designer working part-time in HKD studio[2], the author chose Hong Kong Space Museum (HKsM) for the DBR of this PhD research. There are two exhibition halls in this museum – the Hall of Space Exploration and the Hall of the Cosmos, the research study mainly focus on the Hall of the Cosmos, which is the author in charge of.

Some of the major workflows towards the production of the exhibition:

- Exhibit / object / topic research: within the collection, in other Hong Kong museums, in the world

[2] HKD is a research-led design studio delivering engaging visitor experiences within gallery and museums nationally and internationally, which based in Margate, UK. (website: http://hkd.uk.com/)

- Follow up research about the exhibits / objects: much as a search for primary sources
- Education: writing catalogue, leaflet, panel text, object lists, website content
- Digital strategy (Interaction Design / Augmented Reality and Spatial Augmented Reality)
- Architecture (Interior / exhibits setting design)
- Spatial design work: large scale in terms of ideas and aesthetics, highly detailed in terms of object dimensions, colours, materials
- Project managing team workflows: creative / scholar colleagues, assistants, registration team, collection management, conservation, design, installation

The design process has been considered a creative method that delivers the design information associated with inter-disciplinary working more efficiently and productively (Yamakawa, 1997). It would be advantageous to develop some methods that can be used to achieve complex museum exhibition work as well as influence communication flow through the design process (Newton, 1995). Through the DBR, the author wants to develop a comprehensive and systematic design process that allows museum designers and curators to cope with the complexities of interactive exhibition narration and digitally augmented museum space, as well as meet curatorial requirements in the real context; strengthen the value of the exhibition by providing inspiring and engaging learning opportunities for each of the visitor. This DBR study will be detailed as 4 steps: 1) analysing the practical problems and current museum context; 2) drafting guiding principle and design solutions with a theoretical framework; 3) evaluating and texting the proposed design in real practice and 4) documenting the conclusion and reflection to produce 'design principles'.

In term of the design process, this DBR project can be divided into six design tasks as shown in **Figure 2.3.3-4**, it produces an extensive and broad range of ideas, views, and suggested plans for designing scientific exhibition projects. The detailed exhibition narrative development for this design-based research project, the featured augmented space design, and how these were informed by visitor requirements, design & development requirements and museum (HKsM) requirements were also carefully analysed, applied and described in **Chapter 8** of the thesis.

Fig 2.3.3-1: The primary design stage in HKD studio.

Source: Photographed by the author, 2015

Fig. 2.3.3-2: The prototype stage of the design augmented space.

Left: Participating children playing the prototyped augmented space for the Moon lander experience;

Middle: Participants protecting the prototyped augmented space - International Space Station from space debris;

Right: A participant surfing through the prototyped augmented space, which mimic the Solar system surfing board.

Source: Photographed by the author, 2017

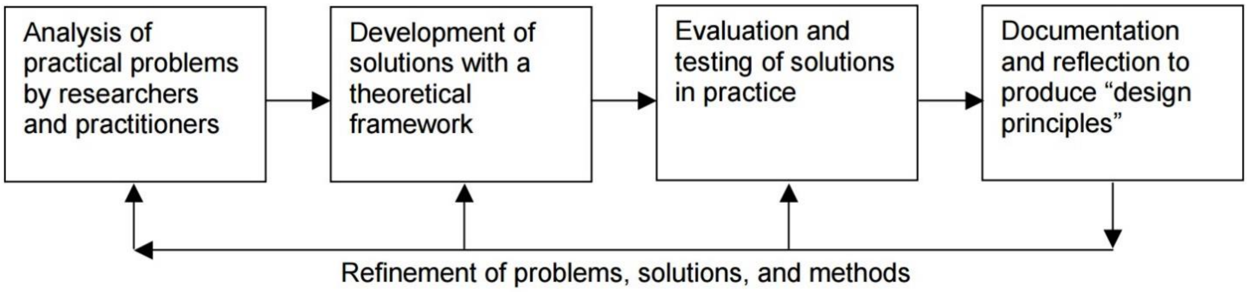


Fig 2.3.3-3: Design-Based Research Diagram

Source: Based on Reeves, 2000.

Task 1	**Task 2**	**Task 3**	**Task 4**	**Task 5**	**Task6**
Conceptual Design	Preliminary Design	Final Design	Fabrication and Production	Installations	Integrated Augmented Design
Equivalent to RIBA stages 1-2	Equivalent to RIBA stage 3	Equivalent to RIBA stage 4	Equivalent to RIBA stage 5	Equivalent to RIBA stage 6	

Fig 2.3.3-4: DBR project can be divided into 6 work tasks, in relation to the **RIBA plan of work (2013)**, from conceptual design to integrated design.

Source: Based on the work plan from HKD Studio, edited by author.

Chapter 3.

Cultural and Historical Perspectives on Scientific Exhibition

Figure: Dam, Steffen (2017). Photograph. The cabinet of curiosities.

Chapter 3. Cultural and Historical Perspectives on Science Museums

3.1 Chapter Overview

This chapter is to provide a brief schematic account of the evolution for science museums development. The author's intention is to select key examples in order to highlight some of the major continuities and shifts within the history of exhibition design, especially in the science museum context. In doing so, the author divides the account into four unequal periods. The first part deals with conceptions of scientific systems in early cultures, then moves to the early modern museums of science. Later, the growth of collecting during the Renaissance fostered the beginnings of 'scientific' ways of knowing. And soon, the development of world fairs and the rapid expansion of public museums of science, represented the beginning of the modern museum. A new approach to exhibition design emphasised a new dedication to combining functionality and aesthetics. In the aftermath of the first introduction of digital technologies in the twenty-first century, in addition to the past-focused industrial heritage and the forward-looking interactive and multimedia display technologies, there is an increased number of exhibitions inside museums of science attempt to interact with their audience in a bigger environmental setting. The issues of augmented reality, digitally augmented materials and embodied interactions around the space also fosters the changes on the digital layer brings for curating scientific exhibitions in science museums. Those augmentations change the original spatial form and act as a new genre of communication for science museums.

3.2 A Schematic Historical Timeline

3.2.1 Conceptions of scientific systems in early cultures

There has been a long history of creating a place to look backward and preserve the early history of human activity. As mentioned by Antonello Marotta in his article, some of the earliest remnants of the human impulse to remember can be found in caves. The earliest forms of proto-museums can be found around the third and second millennia BC, as those palaces, temples, and libraries of Mesopotamia, where the preservation and communication of knowledge began (Marotta, 2012).

However, as Forster claimed, the word 'Museum' was first revived in 15th-century Europe, and it did not come into general usage until the late sixteenth century (Forster, 1961). The word 'Museum' derived from Mouseion, which means 'a temple of the Muses'. More specifically, as it is mentioned by Paula Yong Lee, the French term 'museum' directly referred to the Hellenistic Mouseion of Alexandria (Lee, 2014). The date of its foundation was 295 BC when a former pupil of Aristoteles was chosen to be in charge of the twin institutions, the Library (as **Figure 3.2.1-1**) and the Mouseion (as **Figure 3.2.1-2**), both of which have a significant impact on the building up of scientific systems in early cultures.

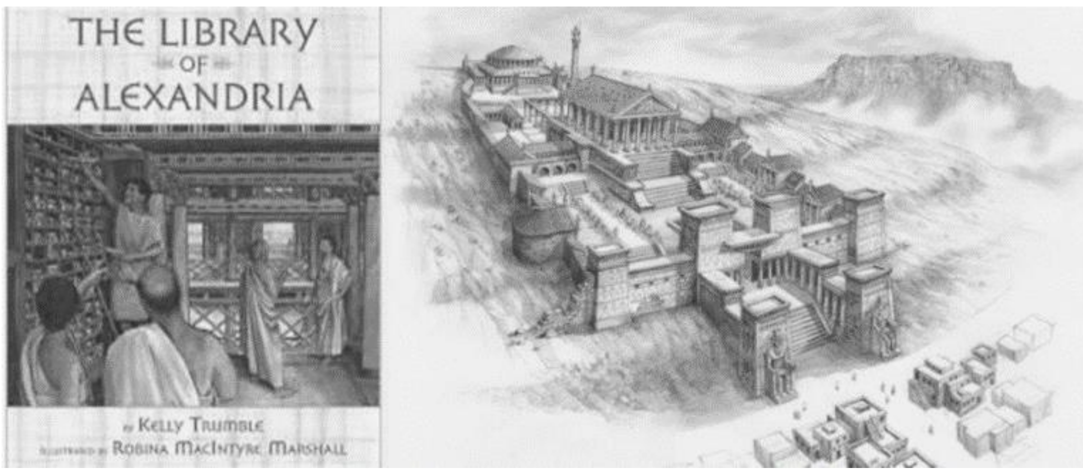


Fig. 3.2.1-1: The Library of Alexandria - the largest library of its time. The Mouseion on the right comprised of several buildings, much like a modern university campus. The main academy building is the Library of Alexandria – it was surrounded by a network of paths, colonnades, and courtyards.

Source: Trumble, K. & Marshall, R., 2003

The institution of libraries has a long history, as many ancient and medieval civilisations have their great libraries, such as in Egypt, Mesopotamia, India, Syria, Greece, Rome and the Islamic world (Findlen, 2000). Unfortunately, all of them have perished beyond redemption due to the passage of time and its vicissitudes. But from what we know, there is no doubt that the most famous among them all was the ancient library of Alexandria for, not only was it the largest in all antiquity, but it was also associated with a remarkable movement of scientific research so that scholars flocked to it from all over the Mediterranean (Fraser, 1972), it soon became a major centre for learning and scholarly research, particularly in the fields of astronomy, geography, mathematics, and medicine (Durrell, 1986). Even after its disappearance with the decline of the ancient world, it continued to survive in the memory of medieval authors, just as its fate continues to be a debated question among scholars to this day.

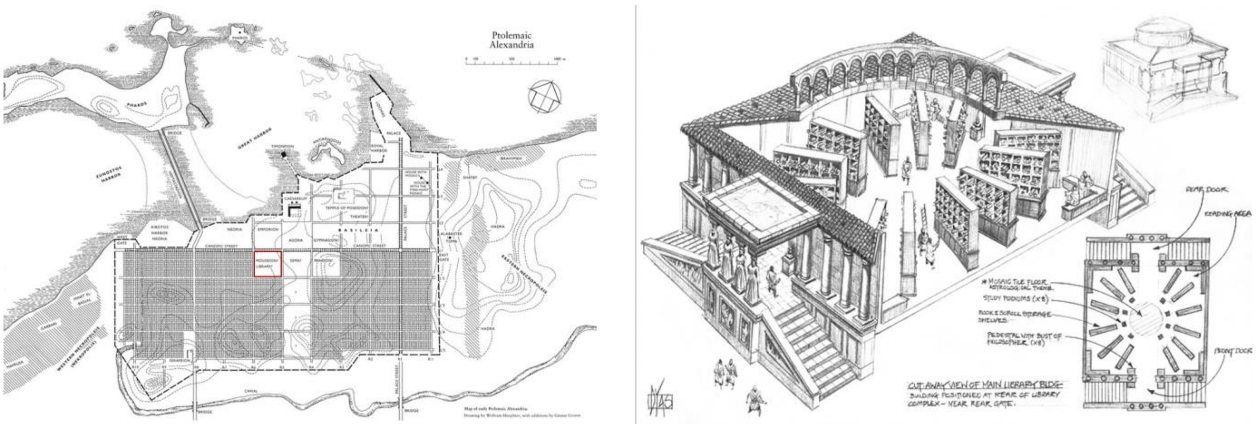


Fig. 2.2.1-2: (Left) Spatial planning of the Mouseion in Alexandria; (Right) The cross-section of the Mouseion

Source: Trumble, K. & Marshall, R., 2003

As regards the Mouseion, it followed the well-known basic patterns of the two famous Athenian philosophic schools, the Academy of Plato and the Lyceum of Aristotle (Empereur, 1998). It was common belief to attribute philosophic and artistic inspiration to the Muses and some sometimes even scientific, as Vitruvius claimed, quoting the story of Pythagoras who believed that he would not have made a certain mathematical discovery, had it not been for the inspiration of the Muses and to whom he sacrificed and gave thanks (Vitruvius & Morgan, 2001). The combination of science and literature was indeed best represented at the Mouseion of Alexandria. The spatial layout of the Mouseion is described by Strabo in the following words: "It was part of the royal palaces, it had a walk peripatos[3], an arcade exedera[4] and a large house in which

3 Peripatos was the name of the beltway-like road that surrounded the Palace along the foothills of the sacred rock at a level slightly higher than the historic Tripodon Street.

4 Exedra was a semicircular recess or plinth, often crowned by a semi-dome, which is sometimes set into a building's façade or is free-standing.

was a refectory for the members, as shown in **Figure 3.2.1-2 (Right)** (Empereur, 1998). Public teaching in the form of lectures and symposia, occasionally attended by the King, may also have taken place and it is generally believed that teaching gradually increased with time. In spite of the fact that by the end of the Ptolemaic rule in Egypt and the arrival of the Romans, scholarship tended to be on the decline, yet the Mouseion in Alexandria still continued to offer the best academic training in the ancient world (Errera, 1997).

In addition to the library, the space of the Mouseion included rooms for the study of astronomy, anatomy and even a zoo of exotic animals (Finashin, 2015). With the founding of these twin institutions, the right approach to scientific studies on a sound basis was established from that moment, and it is perhaps no exaggeration to say that for the first time, the principles of a scientific method of research were developed in various disciplines with highly impressive results in physics, geography, mathematics, medicine and biology… (Forster, 1961). The Mouseion of Alexandria can be regarded as a hybrid born of science and philosophy, with its research centres, laboratories, and technical communities (Bazin, 1967).

As the Mouseion of Alexandria first formed the conceptions of a space embodying scientific system and proto-museum from the ancient and medieval civilisations. After that, a mnemonic technique based on spatial and visual logics, the memory palace took root in Ancient Rome (Uricchio, 2012), where the visitors essentially mapped memories into an imaginary architectural space by rehearsing the passage through space (or remembering an already familiar space), and mentally adorning the room with distinctive visual associations, so, not only can the 'palace' serve as an organised repository of changeable memory cues, but the user can easily change their routes and access different 'rooms' and their memory cues more or less on demand.

With newly awakened interest in a golden past, especially in the beginning of the Renaissance, the desire to remember the past and make a new legacy intensified. An architecture as a repository of miscellaneous knowledge and relics was demanded by scholars. With this background, the perception of the museum as a theatre began to emerge from the 16th century as it is mentioned by Antonello Marotta, it was with two parallel strands, the theatre of memory and the theatre of nature (Marotta, 2012). But Camillo's theatre was different from the memory palace, as it was not a unique creation of each individual's imagination, but rather Camillo's invention, drawn and as far as we know and prototyped, there for other users to share. It was a public place.

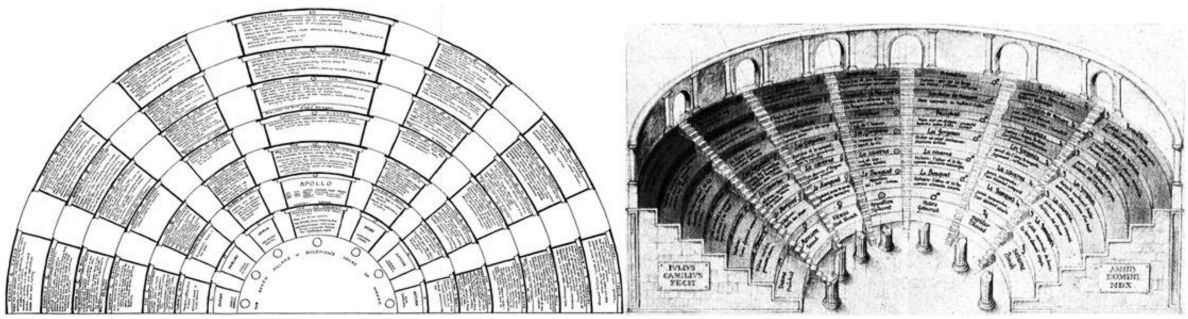


Fig. 3.2.1-3: (Left) The plan of the memory theatre by Giulio Camillo; (Right) The theatre of memory in 3D.

Source: Akademie Verlag, 2000

This place reveales a coherent system of cultural knowledge, a taxonomy of early scientific references and beliefs, complete with scrolls and visual signs. What is so striking about Camillo's construction is that it should take a seemingly abstract idea (memory based on place theory) and turn it into a real structure. His theatre embodied the idea inherent in the tradition of the 'art of memory' that knowledge rested on memory and that the act of remembering rested on the minds ability to 'see'. That this happened in physically real structures with real pictures and objects provided an embodiment of a metaphorical ideal in which museums could effectively take up residence- a place crowded with things that triggered acts of memory leading to knowledge.

In other word, Camillo's theatre functions as a systematic repository of information, which plays an important role in forming the first conception of the science museum in early cultures. And soon in the mid sixteenth Century, Ulisses Aldrovandi began to assemble the collection of zoological and botanical specimens, as the theatre of natural (Marotta, 2012). Almost at the same time, Wunderkammern, also known as the cabinet of curiosity, which started a new chapter of the evolution of science museums.

3.2.2 The cabinet of curiosity – from collection to exhibition

In terms of museums of science, their origins can generally be traced to the curiosity cabinets **(Figure 3.2.2-1)** of Renaissance princes and scholars in the sixteenth Century (Bedini, 1965; Findlen, 1994; Impey & MacGregor, 1985).

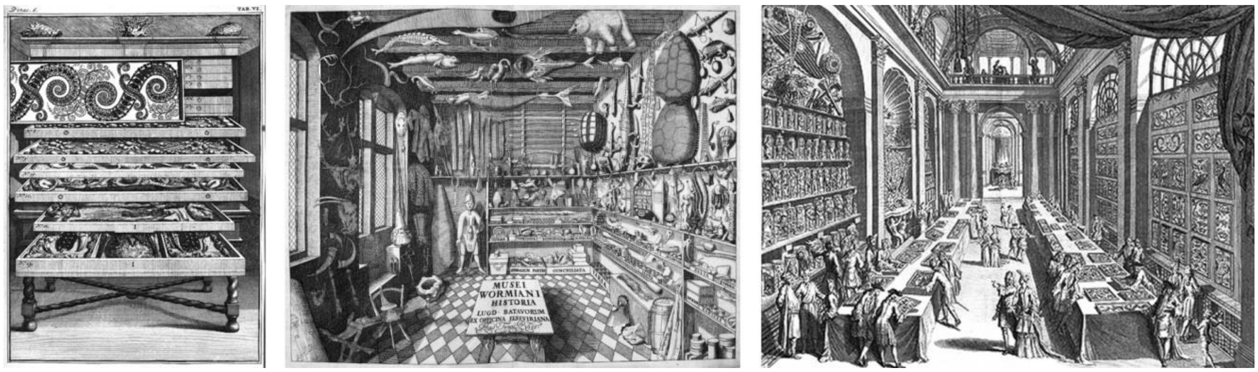


Fig. 3.2.2-1: Three illustrations of those original natural history cabinets.

Source: Ferrante Imperato's Dell'Historia Naturale (Naples, 1599)

Though often an absolute given, thinking about how objects relate to their physical and architectural contexts can also be liberating and inspirational. From the spatial features of the scientific exhibiting in the seventeenth century, in making those natural history cabinets more attractive, architecture and interior design played an irreplaceable role to strengthen the exhibition effect. The physical setting designed by seventieth century architects or artisans often had a strong architectural metaphor, but often became more important than exhibits in terms of its educational values. Even exotic items including ivory, enamels and soapstone were among the exhibits, but according to descriptions, most of them were just for abundant decoration. In most instances, those natural history cabinets are viewed as pieces of highly-decorated furniture, made from all imaginable exotic and expensive materials and filled with contents and ornamental details intended to reflect the entire cosmos on a miniature scale (Alexander, 1995), which makes the final assemblage exhibited in space reveals a strong connection between the natural and the manmade, creativity and instruments. It acted as a strange bridge between atavistic myth and dawning scientific reality (Hoare, 2014).

It also anticipated the idea of the museum as entertainment and opened the way to presentation techniques more akin to those found in many new facilities (Marotta, 2012). Those collections which started by the father, was further expanded by the son, collection itself gradually grew to be an enormous one and was eventually opened to the curious public. As in 1659, when the collection passed into the hands of Elias Ashmole, and he presented the collection to the University of Oxford, with the belief that the study of nature was 'very necessaries to humaine life, health, and the conveniences there of' (MacGregor, 1985). The original collection was sorted, catalogued and winnowed out in the university, and this randomly acquired cabinet of curiosities was taken over by the modern museum. This renaissance approach to collection and display survives in various forms even today. Inside the Pitt Rivers Museum, Oxford, it keeps the original form and exists as an excellent example of a modern curiosity cabinet with modern collection methods, meanings and purposes (History of the wunderkammern, 2003). The museum is a typical example of Victorian Gothic architecture, although the large glass roof over the central part of the museum with cast iron shafts gives visitors a much lighter impression and provides them an open-plan space in the central hall, which has a number of black-framed cases containing natural artefacts by its sequence, as it shown in **Figure 3.2.2-2**.

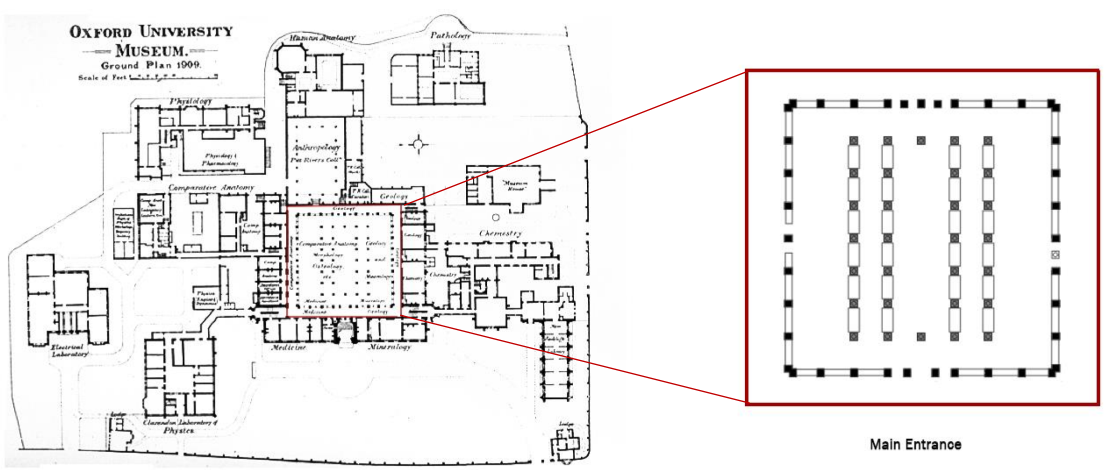


Fig. 3.2.2-2: The central hall of Pitt Rivers Museum still adopted the concept of cabinet of curiosities.
Source: Oxford University Museum's Achieve, edited by author

According to Imogen Burrell, the central hall space today still does not incorporate 3D technology, and there are no electronic display, digital learning materials, interactivity devices nor hand-held guides within its physical facility (Burrell, 2013). However, the absence of technology within the museum does not make it less significant than other museums. The simple, airy, open-plan layout space contains modern curiosity cabinets which act as physical 'augmentation', visitors are able to move freely from one cabinet to another to observe a cornucopia of entomology, taxidermy and animal skeletons which trigger the "wow effect". The exhibition space attempts to make the exhibit more interesting and worth exploring, by appearing to offer choice to the visitor. Alternative and self-discovering routes are provided to them, so that they may have short and fragmented axial paths to be aware of several things simultaneously. In conclusion, collections assembled by those cabinets not only helped in shaping the collective knowledge, but helped to instantiate new concepts in developing scientific method.

3.2.3 Display changes and exhibition modernisation

While universal exhibitions, which were largely concerned with industry and technology, and most museums established in this period, with the exception of art galleries, could be seen as broadly scientific (Forgan, 1996), the nineteenth century is also characterised by the development of more specialised public museums of science. Many of the earliest of these, some of which were established in the late eighteenth century, were devoted to natural history, as was the Musée d'Histoire Naturelle, which opened in Paris in 1793 or Charles Willson Peale's Museum in Philadelphia (1784), though this also included some scientific and technological artefacts (Bedini, 1965). So too were many of the first 'scientific' museums to open in the New World (Sheets-Pyenson, 1989). Anthropology collections were sometimes incorporated in the natural history museums, as in the case of the Smithsonian's Museum of Natural History, the Chicago Field Museum or the Dutch Museum of Natural History, or as part of national self-representations as in the case of the National Museum of Denmark (1916). Museums specialising in machines and technical and scientific instruments also became a distinct type in the nineteenth century, beginning with France's Conservatoire National des Arts et Métiers, which was established in 1794. More specialist science museums often developed out of more general collections, as at the Museum of the History of Science, Oxford, which originated from the Ashmolean collection and the Natural History Museum, London, which originates from the British Museum collections (Hackman, 1992).

The architectural space was designed by Francis Fowke and Alfred Waterhouse and it soon became Britain's most striking example of Romanesque architecture, which is considered a work of art in its own right and has become one of London's most iconic landmarks (History and architecture / NHM, N.D.). The architecture of the Natural History Museum can be seen as a 'cathedral' of the creations, and the museum identity is expressed by the idea of imperial wealth manifested through the encyclopaedic collection (Psarra, 2009). The creator and first director of the Natural History Museum was Professor Richard Owen. The building was opened to the public in 1881, and the story of its design is reported by Mark Girouard (Girouard, 1981). According to its first proposal, the ground floor was basically organised as a comb-like plan with a hall at the centre of its major axis (**Figure 3.2.3-1**) (Peponis & Hedin, 1982). The central hall acted as a fulcrum from which all parts branched off. This helped to differentiate the departments of skeletons and specimens of animals while the central hall acted as an index to the museum as a whole.

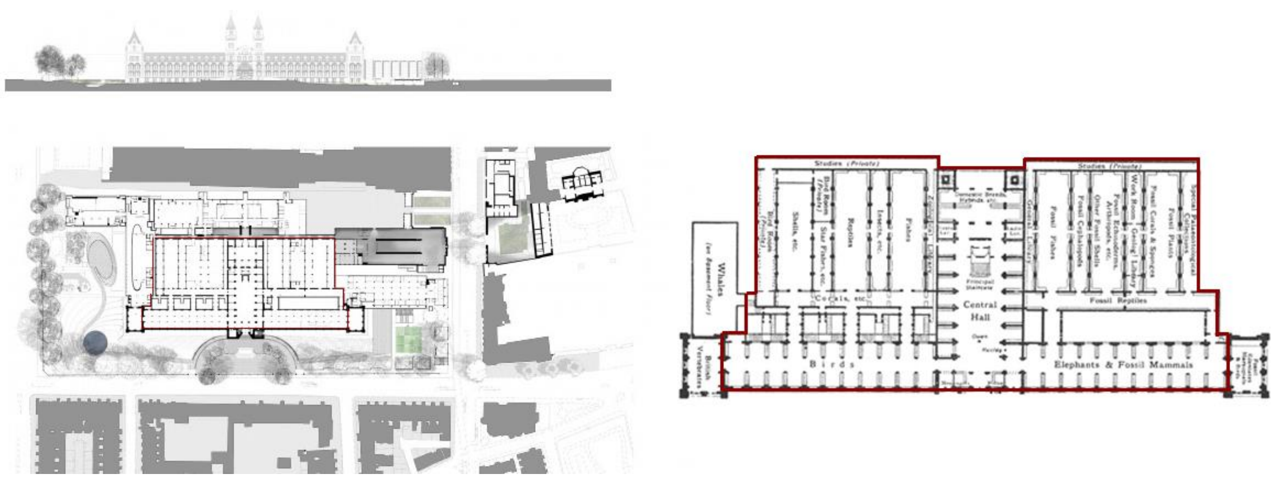


Fig. 3.2.3-1: The Layout of the central hall inside Natural History Museum, London, a 'cathedral' of the creations.

Source: History and architecture, NHM, N.D.

The museum space adopted natural history as a science of classification, and the space inside each gallery was also carefully designed to provide an instructive framework for most exhibits, as the museum literature offered to visitors affirms. According to the director of the Natural History Museum, London, Sir William

Henry Flower, the curator carefully considered the capacities of the audiences, the variety of objects, and the available gallery space. In this case, different subjects were carefully divided and illustrated into groups, considering their relative proportions and according to the planned gallery space.

In each gallery, there were certain propositions to be illustrated, either in the classification, genetic structure, geological position or geographical distribution, the primitive instinct for survival, or evolution of the subjects dealt with. Since both museum structure and gallery space were 'strongly correspond to a scheme where knowledge is inherently spatially' (Psarra, 2009). When seeing and knowing were closely related as in 'classification', the process of transmission of knowledge was not very different from that of acquisition. What expert knew was the same classification that was made visible to visitors. However, this also meant visitors were instructed to visit following the fixed journey to avoid the 'discontinuities' in knowledge. As it has been affirmed 'the layout of the exhibition space affects the narrative, because things placed together will look logically connected, and things separated will be seen as logically distinct.' (Miles, 1979)

The Palais de la Decouverte ("Discovery Palace") can be regarded as the first science centre that took education as its main purpose (Hudson, 1987). Unlike traditional science museums, it did not concern itself primarily with the preservation of artefacts. Instead, this discovery palace describes itself as 'a scientific cultural centre' in which a large number of scientific experiments were (and still are) demonstrated to visitors (Hudson 1987). According to its founder, Jean Perrin, one of the objectives of the Palais was to realise the potential for scientific research which he hoped might be found in the population at large, and the whole concept of the institute was formed around the idea of education. As it is described in the book - Exhibiting Cultures, the Poetics and Politics of Museum Display, it targeted from the youngest child to the oldest adult (Karp & Levine, 1991). Both the exhibitions and the demonstrations given by guides were planned from an educational point of view.

Fig. 3.2.3-2: The Palais de la Decouverte, Paris, in 1985.

Source: History and architecture, NHM, N.D.

3.2.4 Interactive exhibitions with augmented reality (AR)

Two thousand years ago, 'science' was studied by technologists as a branch of politics and religion, but today scientific knowledge has been enormously expanded to embrace many disciplines such as Physics, Chemistry, Mathematics, Biology, Astronomy and Natural History. In other words, a scientific study covers the entire natural and human world, including industry, built environment and computing technology. As Macdonald states: "Science in the late twentieth century was widely conceived of as difficult and abstruse, a matter for every specialised expertise" (Macdonald, 2006). As the body of science is expanding at an accelerating rate, the idea of modern science museums keeps evolving as well.

Science museums were largely adopting the rhetoric and exhibition techniques that the Exploratorium pioneered because the designed exhibitions 'let the visitor be the laboratory subjects of their own perceptual experiments' (Hein, 1990). The intended effect of this pedagogic strategy was not just to teach perceptual theory, but to encourage the visitor to experience the process of discovery and thus to become an experimenter. This extraordinary enthusiasm for interactivity, which had been initiated by the Exploratorium, has subsequently spread across the world. In the meanwhile, many researchers noticed that the interactivity in many modern science museums was simply a copy of the American original. As sociologists of technology have been at pains to argue, the process whereby a technology is 'transferred' from one place to another should be thought of as a form of translation or reinterpretation rather than merely a form of diffusion (Latour, 1986). In the UK, the radical concerns of the American centre with the issue of empowerment were marginalised and, with exceptions, Oppenheimer's interests in the links between science and art were ignored at the time. Instead, interactivity came to operate in relation to the failure of the traditional science museum to address a rather more mundane set of concerns with the public understanding of science and the attractiveness of the museum to visitors.

However, the recognition that visitors came to interactive science centres and exhibitions to enjoy themselves created a problem for proponents of interactivity (Gregory, 1989). In the view of their designers, interactive exhibits were always expected to be as many instruments of informal education as a means of entertainment. The museum visitor was conceived of as an active learner, and not just as a consumer. Critics pointed to the lack of historical or industrial contextualisation of many interactive exhibits and the frequent absence of any explanation of what scientific principles were supposed to be revealed through the process of interaction. Some exhibits, it was said, can be interpreted in ways which lead museum visitors to false conclusions.

Indeed, it is unclear "whether any of the scientific principles that many interactives are meant to demonstrate would be grasped by any except those already possessing a good scientific education" (Barry, 1995). As Sharon Macdonald suggests, the failure of interactives to communicate scientific principles may, in part, reflect the limitations of the museum as a medium: "museums might not be particularly good…at getting across scientific facts and details, then furthering understanding through more general images and messages about the nature of science, its possibilities, its relevance and its limitations" (Macdonald, 1992) Moreover, some question whether many interactive devices are really interactive. Many so-called interactive touchscreen computers "simply allow the visitor to select from a predetermined set of options". Interactivity like that is "far from providing the possibilities for experimentation", "such interactive devices may merely serve to create the illusion of choice" (Strathern, 1992). With the aim to build up new and innovative interactive exhibition concepts, science museums and science centres nowadays widely adopted augmented technology to carry out social and cultural agendas (Quistgaarda & Kahr-Højlandb, 2010). Evolved from historical / aesthetic representations into immersive learning objects using cognitive load and constructivist theories, modern science centres and museums saw Augmented Reality as a possibility for new ways of communication and engagement styles with the visitors (Hsi & Fait, 2005; Hornecker & Stifter, 2006; Dindler et al., 2009).

Those augmentations provide museums a lot of new opportunities, but one of the most essential is the fact that these augmented technologies allows for completely different interactions and activities that otherwise would not be feasible (Hawkey, 2004). Hawkey also emphasises the power of the technology when it comes to learning in the museum, and that a different range of media can disseminate knowledge (Hawkey, 2004). On the other hand, knowledge becoming limitless for the museum visitors, because with augmented technologies, visitors are continuously connected to the internet wirelessly, and are therefore are provided with real time data in any location in which they are situated. Taxén also discusses the wide variety of the technology that is used in the museums, and points out that application of these has as a goal to "augment, enhance or replace traditional exhibition techniques" (Taxen, 2005), and "will totally change the existing visitor experience" (Sharp et al., 2009) in more and more museums.

3.3 Chapter Conclusion

This chapter provides a schematic historical timeline as an overview of historical context and cultural perspectives on science museums. This chapter starts from the emergence of the word 'Museum', which can be derived from Mouseion of Alexandria in in early cultures. Then it moves to the Early Renaissance, when encyclopaedic collections of objects (normally known as cabinets of curiosities) emerged, and the 17th century saw the beginning of change in the criteria for authenticating and validating scientific findings, with the growth of taxonomic knowledge based upon new ideas of order, visibility and objective observation in the first half of the century. The second half of the century sees the process of producing scientific knowledge become increasingly associated with, and dependent upon, the methods employed in its dissemination - with processes for transforming private insights into public knowledge. The 18th century sees further changes in the science museum field. In particular, an 'opening up' of the museum to a much broader public, is also connecting with the changing conceptions of scientific authority.

The following years saw the display changes and scientific exhibition modernisation, museums came to be conceived as 'symbols of national identity and progress', and as 'sites of civic education for the masses' (Hooper-Greenhill, 1992; Kaplan 1994; Bennett, 1995; Duncan, 1995). In the meanwhile, much of the 19th century science museum moves from 'museological science' to 'experimental science', which entails 'control over phenomena in laboratories' (Pickstone, 1994). It heralds a renewed significance in its role in 'the public understanding of science', and builds a solid foundation for the widespread popularity of hands-on exhibits. With existing museums of science coming adopt new technologies of display, new interpretive experiments and new concerns with their visitors and communities, a massive expansion of two particular forms including industrial heritage and science centres are revealed in the 20th century.

From the 21st century, science museums started to step into the digital era with more and more new media and advanced technologies being widely adopted in museums for interactive and immersive experience-making. This extraordinary enthusiasm for interactivity has been gradually spread across the world. However, many of those failed completely, because interactivity in many science museums was imitate, and many so-called interactive exhibits 'just allow the visitor to select from a predetermined set of options' with zero 'social and cultural agendas' (Strathern, 1992; Macdonald, 1992; Quistgaarda & Kahr-Højlandb, 2010). In light of the above concerns, Augmented Reality (AR) is promising technologies which have wide impact on creating new interaction approaches, and at the same time, are not commonly associated with traditional Human Computer Interaction (HCI) methods. AR provides direct displaying information related to real objects and projects into real physical space that visitors are currently perceiving. This new spatial format has a great potential to attract the audiences and increase their engagements, interests, and usability with new museum experience.

Through the literature research, the author captures the relation between science museum evolution, museum space, technology development, interactivity and new augmentation to review the process in historical context and cultural perspectives on science museums emerged and developed in past centuries. With special focus on the impact of the computer age and digital culture in the technological landscape of the 21st century. Moreover, with those advanced augmented technologies, museums are now able to build new relations between visitors, exhibits and museum space. However, according to Gustav Taxen's doctorial research, the introduction of different digital devices into the museums and science centres, requires experimenting with the technology´s possibilities and affordance (Taxen, 2005). In order to contribute to affordance or the other design principles such as visibility, constraints or consistency that are vital for the user experience (Sharp et al., 2009); there is a need of perspectives and knowledge from the field of interaction design and augmented technologies for museum designers. The emphases of this part of the research will be laid out in the next chapter.

Chapter 4.

From Augmented Reality to Augmented Space

Figure: Bottazzi, Roberto and Klein, Tobias. (2010). Augmented Space in the Molecular City

Chapter4. From Augmented Reality (AR) to Augmented Space

4.1 Chapter Overview

Digital technologies have been well integrated into our daily lives in this age of information. The continuous miniaturisation of digital technologies allows computers to be portable and ubiquitous. Technologies like Augmented Reality (AR) offer a new approach towards human-computer interaction via directly displaying information related to real objects and real space that people are currently perceiving. And user's sensory perceptions are enhanced (augmented) with information of interest naturally without deliberately turning to computers. Recent advances in mobile technology have made computationally intensive AR applications become even more widely available. Based on mobile technologies that continuously connected to wireless network, real time information could be presented virtually within different physical spaces to create this immersive environment that seem possible to 'entre' them (Grau, 2003). The boundaries between real and unreal, private and public are breaking down allowing users to experience narratives through a form of 'qualculative sense[5]' (Thrift, 2004).

How to characterise the idea of 'augmented space' more precisely? The author wants to argue that the best way of thinking about this characterisation is to go back to review the fundamental components of an AR system. With the study of those AR components, it suggests techniques as well as narratives of ways to create immersive engaging environments within physical spaces. These characteristics of AR technologies further facilitate the transformation between the physical spaces and real-time, active instantaneous positioning environment, which bridging physical and digital, allowing new forms of spatial interaction & experience and eventually mediating social & cultural changes and transforming 'space' to 'place'. The author explores many new concepts responsible for the re-conceptualisation of augmented

[5] In Thrift's thesis, this new 'qualculative sense' involves a different sense of number and counting and series, a sense which relies on (1) a series of prostheses which routinely offer cognitive assistance and which do much of the work of navigation automatically, (2) a highly provisional sense of spatial co-ordination which is based in the continual spatial and temporal revisions made possible by track and trace systems (the so-called 'elasticity of synchronicity'), (3) a sense of continual access to information (so-called 'ambient information') arising out of connectivity being embedded in all manner of objects, which means that the effort involved in foraging is much less than was the case, (4) a more flexible sense of metric and (5) much less sense of locations as places of return or permanent gathering of the kind constructed around the institution of the domestic house in Euro-American societies from the fourteenth century onwards (Thrift, 2004).

space. It draws some conclusion and suggests directions for the contextualisation of AR technology within the evolutionary process.

4.2 Augmented Reality for Museum Environments

AR system is well known as enhancing (augmented) museum space via adding the extra dimension of the knowledge transfer method, which is also the focus of this thesis. As the thesis has mentioned in the last Chapter, recent augmented reality technologies are able to provide solutions of enabling visualisation of 3D digital models of museum artefacts, and merging both virtual and real physical layers into an integrated environment. With AR system embedding within the museum environment, the users are able to interact with immersive digital contents as in a real world. Apart from the ARCHEOGUIDE mentioned above, there's thousands of AR applications & systems which have been adopted in the museum environment. These adoptions help museums to visualise a better scenario which allows visitors to interact with the museum contents in an explorative, exciting, and intuitive manner.

An earlier example of AR system in museum is the Virtual Dig Experience installed in the Seattle Art Museum (Virtual Dig[6], 2003). The museum exhibit and surrounding physical environment were using VR and AR techniques to encourage its visitors to discover themselves, with both artefacts and their archaeological context presented together - real objects such as small shovels, brushes and Amplifying lens are used for interactive exploration[7]. This Virtual Dig has been developed based on the ARToolKit (ARToolKit 2003) and HI-SPACE (HISPACE, 2003) packages. With the development of mobile devices like smartphones and tablets encompass all the hardware to implement AR system, more and more museums started to replace see-through devices with hand-held devices inside museums (**Figure 4.2-1**).

[6] http://www.hitl.washington.edu/projects/sichuan/

[7] For the Virtual Dig, participants are asked by the museum narrator to help in excavating a new site in the Sichuan province, China. The tool they are instructed to use is an ordinary 1-inch paintbrush. Because the video based tracking system uses normal objects and not specialised devices, almost anything can be used to interact with the computer. Participants use the brushes to remove grass and dirt to expose the first artifact layer.

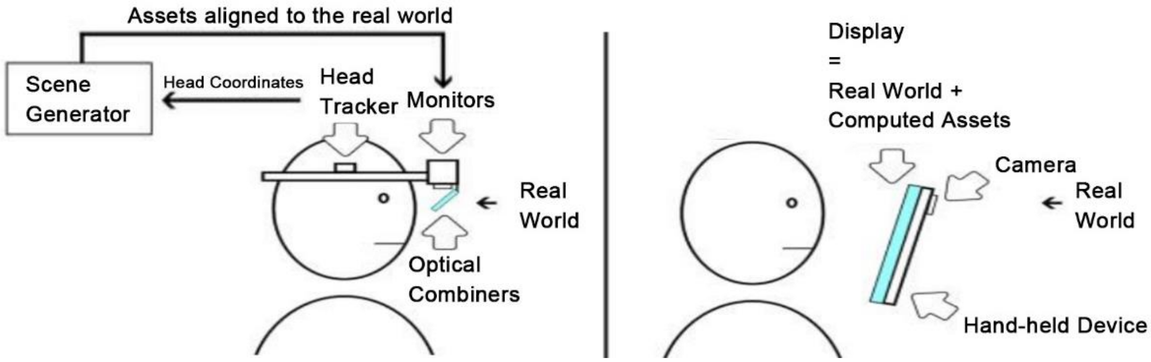


Fig. 4.2-1: The see-through paradigm (left): the user is able to see the real world with his/her own eyes and assets are overlapped by an optical combiner. The hand-held paradigm (right): the user perceives the real world through the video streaming coming from the camera and assets are overlapped by a video combiner.

Source: 'A Survey on Applications of Augmented Reality' by Federico Manuri and Andrea Sanna, 2016

Furthermore, an increasing numbers of museum experts and educationists worldwide believe that spatial display configurations can be as even beneficial for visitors in museum. Novel approaches in recent years have taken AR devices and systems beyond traditional eye-worn or hand-held displays to enable additional application areas – there's new display paradigms which exploit larger spatially-aligned optical elements, such as holograms, mirror beam combiners, transparent screens and video projectors (Bimber and Raskar, 2005) as shown in **Figure. 4.2-2**.

Fig. 4.2-2: The see-through paradigm (left): the user is able to see the real world with his/her own eyes and assets are overlapped by an optical combiner. The hand-held paradigm (right): the user perceives the real world through the video streaming coming from the camera and assets are overlapped by a video combiner.

Source: 'A Survey on Applications of Augmented Reality' by Federico Manuri and Andrea Sanna, 2016

In the early 1990s, projection-based surround screen displays became popular. One of the most well-known example is a multi-sided, immersive projection room. But there are other examples of semi-immersive wall-like and table-like displays or immersive spherical spatial displays (Bimber and Raskar, 2005). As increasingly AR technologies involved with larger spatially-aligned optical elements, this new AR technological variation started to be recognised as spatial augmented reality. As Oliver Bimber and Ramesh Raskar claimed, spatial augmented reality provides museum environment brand new digital storytelling and next-generation edutainment tools (e.g., Virtual Showcase and Augmented Paintings). Spatial AR makes use of projection technology and decouples the display surface from the related display device. Acting as display devices, digital projectors are used to facilitate the display of computer-generated (virtual) imagery on physical surfaces, as **Figure. 4.2-3.** The decoupling of display devices and surfaces has the potential to provide a more natural way of museum visitor interaction, as the virtual information registered to physical objects is directly integrated in the real physical world of museum space. The detail of how to augment museum space via spatial augmented technologies will be further discussed in **Chapter 5**.

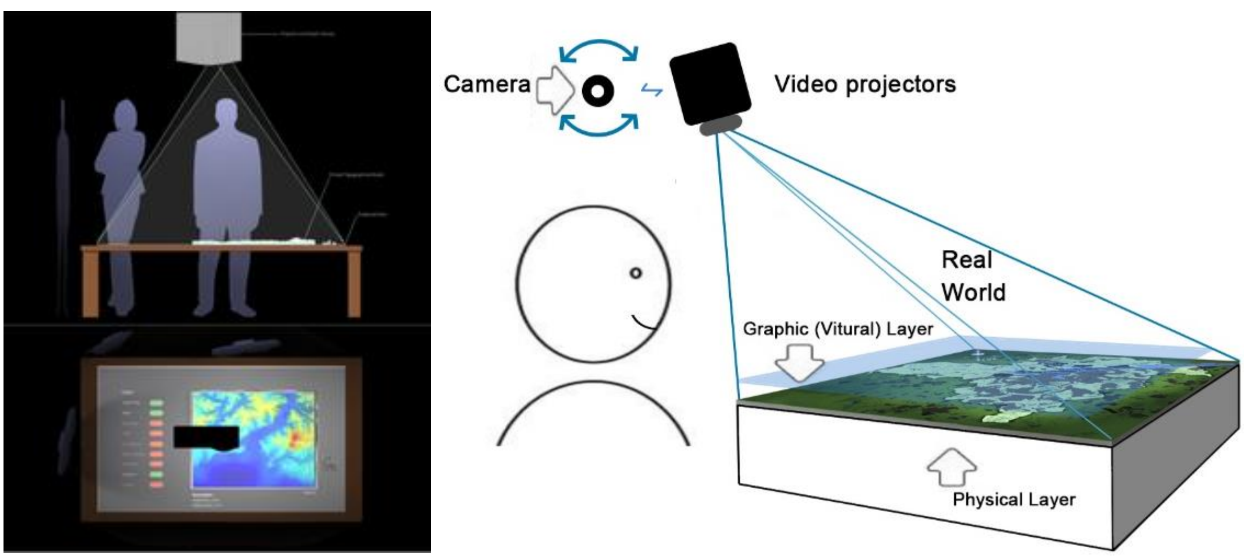


Fig. 4.2-3: The spatial augmented reality (SAR) paradigm.

4.3 Embedding the Spatial Augmentation in Museums

As the author mentioned in Chapter 3, the realisation of the Spatial Augmented Reality (SAR) is always linked the space with augmented technologies, and it can be retrofitted to existing spaces or exhibition designs to unlock new layers of content from text, audio, video or 3D. In short, it can create a visual application for the next generation museum that is adaptable, updatable and viewable without extensive hardware (Poulson, 2016). Spatial AR becomes increasingly feasible as projectors and computer systems decrease in size, weight, cost and power consumption, according to Beardsley et al. (2005), Raskar et al. (2001) and Jones et al. (2010). The trend towards the miniaturisation of projectors and companies' test cases of smartphones with embedded projectors. In order to better analyse related work and respective attempts towards functional systems in museums, the author divides the field into four building components: Interaction, Scene, Technology, and Application. A small description of each follows in this section and an illustration is provided in **Figure 4.3-1.**

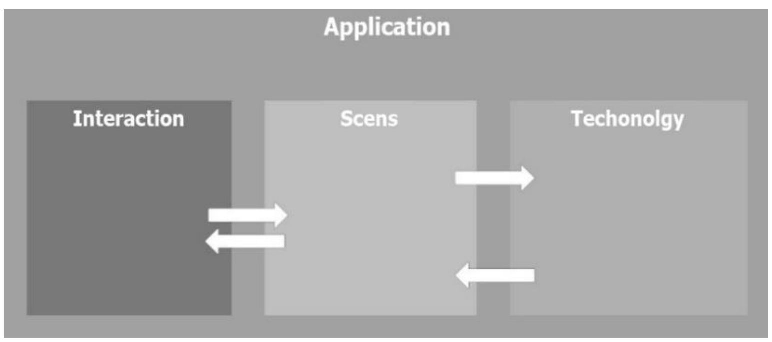


Fig. 4.3-1: Structure of the building components of SAR (Interaction, Scene, Technology, and Application) and their in-between relationships.

Source: Illustrated by the author

A museum visitor, in order to communicate with the system, has to perform specific actions. For this, special support needs to be designed and implemented in the museum environment. The support for interaction basically involves the means to provide user input and an interface with supported functionality to the system. Moving on to the next component, the scene is linked to the museum environment of the SAR setting. All the objects that have a specific role in the setting belong to the scene. For example, the object / exhibit, on which the virtual content is projected, is a part of the scene. Next, the technology used to create a SAR system in a museum setting is being discussed in the corresponding component. Technology, such as larger display devices, tracking and registration techniques for museum visitors, are included in this section. Finally, a SAR is strongly connected to the informal learning in the museum that it serves. Therefore, the application component provides an overview of the learning factors where the Spatial AR has been applied.

4.3.1 Achieving spatial interaction

Since Spatial Augmented Reality is the technique applied in the real physical world, it instantly inherits some natural aspects of human interaction. Nevertheless, SAR is still be treated as a technology nowadays, and this fact attribute to the interaction of the machine entity into the interaction. The implication is that in a SAR setup inside the museum, we still have to deal with human-computer interaction, but since the real world (physical space) plays an important role, the interaction must be more abstract, and embed features of natural human interaction.

As mentioned previously, the term interaction refers to the user's action in order to communicate with the system. Consequently, in the museum environment, the visitors are the one to interact with the SAR system, therefore, victors are entities for whom the support is built for. Characteristics such as mobility and number of visitors play a role in the interaction. For example, a visitor that tend to stay at the same position (static) to observe and another visitor that moves around in the museum environment (dynamic) to explore what interests him/her the best will probably use different means to interact with the SAR system. Moreover, the visitors have to provide input to the system, which can be obtained, either from a single, or multiple sources. The input is mainly divided into two categories: action via visitor's body parts and action via extra tools. In both categories, the input can be basically anything. Nevertheless, the most common input in the first category, is input provided by tracking visitor's head, hand(s), finger(s) and speech. In the second category, the most common is a tracked device such as a digital pen or a tangible AR tile. Of course, any other artefact falls into this category. Apart from user input, it is common that the museum visitors need additional support to interface the SAR system. A menu with options is widely used as a user interface to a SAR system.

From this point and on, the author goes through the literature and discuss the most common features that are used in order to achieve interaction with a SAR system in museum. Some of the works use a conventional/standard mouse, in order to provide visitor input. This form of input is common in classical human computer interaction. Tonn et al. (2008) used a mouse and a laser pointer to interact with a SAR system that facilitates interactive museum scenarios (Tonn et al., 2008). In the same work, the visitors access the system via a Graphical User Interface (GUI) running on the same computer as the SAR application. The same applies for Han et al. (2006), who extend the interface of standard desktop applications into physical environments (**Figure 4.3.1-1 a**) (Han et al., 2006). Similar to the input via mouse, a game controller has also been adapted, enabling the visitors to interact with the application in SAR. Moving a step forward, the attachment of a marker to a fingertip detaches the input from the confines of the conventional mouse (**Figure 4.3.1-1 b**). In the same sense, retro-reflective stickers, which can be attached to any object, have the power to transform an object into an input device itself, according to Verlinden et al. (2003) and Dorfmuller (1999). In 2001, Chan and his colleagues developed a 3D user interface - the "MagicPad" - which is a planar small surface (pad), tracked in space, on which virtual imagery is projected and offers properties such as scaling and rotation (Chan & Lau, 2001). Similarly, Ehnes et al. (2004) project options to a planar surface, in order for the user to interface the system (**Figure 4.3.1-1 c**). They mention that the user input is provided by a tracked infrared pen with a LED on its tip, nevertheless, they have not implemented it in this work. It seems that the tracked pen is a typical solution reported in several research works (Cao, 2007; Bandyopadhyay, 2001; Jones, 2010 and Smith, 2011). More specifically, Jones and his colleagues built a surface interaction engine to decouple content creation from the display surface, it allows visitors to build their own physical world, map virtual content onto the physical construction and play directly with the surface using a stylus (Jones et al., 2010). This kind of infrared-emitting pen is used to interact with projected virtual content and a menu is projected to provide options onto a specified by the user location, as shown in **Figure 4.3.1-1 d.**

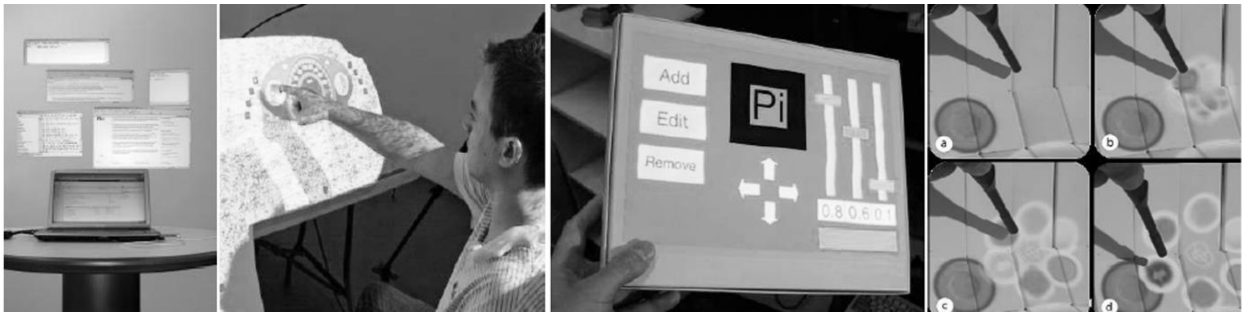


Fig. 4.3.1-1: Interaction in SAR: a) Extended desktop to wall interaction via mouse (Han, 2006); b) Attachment of marker to fingertip for user input (Porter, 2010); c) Menu tracked and projected onto a panel (Ehnes, 2004); d) Tracked pen and radial menu in *Build Your World and Play in It* (Jones, 2010).

The literature also reports the use of the handheld projector for visitors input for museum environment. Beardsley et al. (2005) factored out the projection motion to create a projection that is static on the display surface, and they left part of the projection (a cursor at the centre of projector image plane) to follow projector's movement. The user sees a static projection, with a cursor moving across it, in response to pointing motion of projector as input (**Figure 4.3.1-2 a**). Lately, an increasing trend towards body part(s) motion tracking has appeared. In "LightSpace", they track the visitor's hand and encode gestures such as 'drag and drop' for interacting with virtual content inside museum environment (Wilson 10). In "OmniTouch", the visitor's finger is tracked and provides input for a number of applications developed to test the concept (Harrison, 2011). See **Figure 4.3.1-2 b** and **Figure 4.3.1-2 c** respectively.

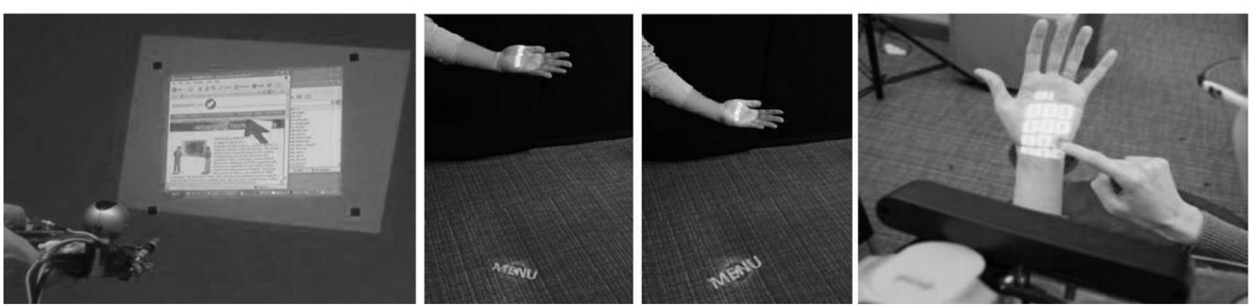


Fig. 4.3.1-2: Interaction in SAR: a) Factored out projection motion creating a static projection and the cursor movement follows the projector movement (Beardsley, 2005); b) LightSpace system: hand tracking as user input and projection of different options of a spatial menu (Wilson, 2010); c) OmniTouch system: user input by finger tracking (Harrison, 2011).

Finally, Mitasova et al. (2006) present a SAR system for real-time motion capture (**Figure 4.3.1-3 a**) and landscape model interaction (**Figure 4.3.1-3 b**), which uses a tangible geospatial modelling environment. The figure shows how the visitors input is inserted in museums to create this tangible user interface with a SAR system, and the manipulation of the deformable surface by the user(s) is one way of those tangible inputs for the system. A final remark here is that the interaction design inside the museum strongly depends on the tracking techniques that are used in each SAR setup.

Fig. 4.3.1-3: a) SAR system for dinosaur exhibition, the visitors input is provided by haptics; b) The change in the deformable surface is the result of the user input (Mitasova, 2006), as a group of students creating landforms using the University of Wyoming's Geological Museum's sandbox and enjoy the embedding SAR system (photo courtesy of Laura Vietti).

At this point, it is important to mention the publication from Elepfandt and his colleagues in 2011, about appropriate interaction in augmented space for museum environments (Elepfandt et al., 2011), as they identify the lack of appropriate interaction techniques in SAR applications through a short research in literature, and propose that the multimodal and touchless interaction is the future for SAR inside museum environment. For touchless interaction, they investigated gaze, speech and gesture, and they propose a combination of them, since each one contains certain advantages and disadvantages. In order to reinforce the suggestion for multimodality, they underline that in human-human communication, speech and gaze are normally used for complementary information, inferring that human interactions are multimodal by nature. An interesting part of their paper is the human interaction in 3D space. The spatial aspects of perception and interaction are introduced, and it is proposed to be taken into account for improving interaction in SAR. They adapt Previc's theoretical model of 3D spatial interaction (**Figure 4.3.1-4 a**), and describe that the peri-personal region is within hand reach, while the three extra-personal regions are out of reach. Hence, one fact is that each region depends on the individual's arm length. The peri-personal behavioural system is characterised by grasping, reaching and manipulating objects, whereas the extra-personal behavioural systems are characterised by the visual search and recognition of objects (focal), navigation and target orientation (action) and spatial orientation, postural control and locomotion (ambient). In 2013, Pezzulo and his colleagues studied the social context of the multisensory integration and sensorimotor motor transformations inside a shared action space, as shown in **Figure 4.3.1-4 b**, which provides a hint for considering both social and spatial factors in embedding augmented space for future museum environment.

Fig. 4.3.1-4: a) Theoretical model of 3D spatial interaction; b) A schematic illustration of "Shared Action Space" (SAS).

4.3.2 Creating immersive scenes

The scene in museums might consist of a single or multiple exhibits. It can be either static or dynamic. In a static scene, exhibits are fixed and remain in the same position. On the other hand, objects can keep "changing" in a dynamic scene. This change refers to two different aspects: the first aspect is that the position and orientation (pose) of the object(s) change, and the second aspect is the fact that an object deforms, meaning that the shape of the exhibit changes. Many different examples of scenes can be found in the literature. At this point, the author chooses to refer to the most representative ones. Tonn and his colleagues used the walls of an exhibition room as a surface to project on, since their application involved in-situ comparison of architectural plans (**Figure 4.3.2-1 a**). The scene in this example consists of the walls on which the virtual content is registered, the scene is apparently static (Tonn et al., 2008). Similar scenes appear in many types of researches (Forlines, 2005; Han, 2006 and Cao, 2007). On the other hand, Jones et al. construct the scene of the system on the fly. This means that the system is designed to operate with a variety of scenes (Jones et al., 2010). As **Figure 4.3.2-1 b** shows, they build a scene out of styrofoam the first time and a scene out of sand the second time. Similarly, to the previous works, the scene is static during the SAR system's operation. It was similar to Bandyopadhyay et al. (2001) use a house model as part of the scene which is being tracked, thus it is dynamic (pose changes). Furthermore, the menu used to interface the system, is also a part of the scene (**Figure 4.3.2-1 c**).

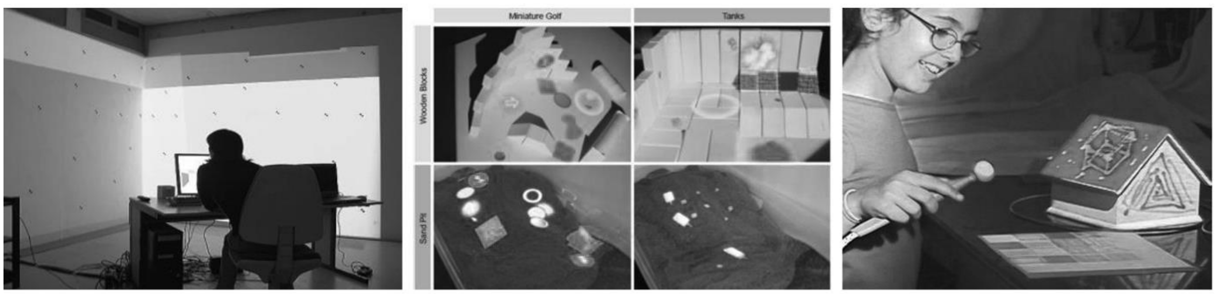


Fig. 4.3.2-1: Scene setups: a) Wall of the room for projection of architectural plans (Tonn, 2008); b) Scene made out of Styrofoam and Sand for game applications in "Build Your World and Play In It" (Jones, 2010); c) A house model and a spatial menu forming the scene (Bandyopadhyay, 2001).

Apart from rigid objects, which can be either static or dynamic in a scene, the museum visitor's body can be encoded to act as a part of the scene too. In "LightSpace" system, the body is used as a surface in order to enable the connection of two other surfaces (as **Figure 4.3.2-2 a**). Therefore, Wilson et al. (2010) use the body as part of the scene. The body is tracked as an entire volume (dynamic). The same applies to "OmniTouch", where one of their application examples is the use of the palm of the hand as an active display surface (**as Figure 4.3.2-2 b**). In the same sense, the hand becomes a part of the scene, which is dynamic and deformable. Another interesting example of a deformable object which is part of the SAR system's scene, is the deformable surface used as a tangible geospatial modelling surface by Mitasova et al. (2006), which refer to Maas et al. (2011) for a deformable material created especially for use in SAR.

Fig. 4.3.2-2: Scene setups: a) Use of the user's body as part of the scene (Wilson, 2010); b) Use of hand as part of the scene (Harrison, 2011); c) Interaction mechanism: full body interaction inside museum (Hespanhol, 2015).

Many studies have established that creating dynamic scenes inside the museum for multi-sensory immersion and interaction increases visitors' emotional engagements and that this connection, in turn, creates more memorable and profound learning experiences (Storgmer, 2010). As it is mentioned by Falk and Dierking, in museum environments, "…AR scene for museum experiences can be deeply embedded in visitors' memories with potential for significant learning" (Falk & Dierking, 2009). There are more scene setups for augmented space in museums as indicated in **Figure 4.3.2-3.**

Fig. 4.3.2-3: More scene setups for augmented space in science museums. left: Create a Chemical Reaction is an interactive exhibit in the Science Storms wing of the Museum of Science and Industry in Chicago. Right: The E-mmersive Experiential Environments (E3) exhibition combines different immersive technologies, it is designed and developed by NorthernLight, is used as a testbed for new forms of engagement in Singapore Science Centre.

Source: Google Images.

4.3.3 Embedding spatial applications

For embedding spatial technologies, several tracking techniques exist and have been deployed to achieve tracking of real world objects in augmented museum space. As the author mentioned, racking research focuses mostly on sensor-based and vision-based (Zhou et al., 2008). Sensor-based tracking techniques are based on sensors such as magnetic, acoustic, inertial, optical, and mechanical, and it is very common in constructing SAR systems inside the museum space. On the other hand, vision-based tracking is an active research area, according to Zhou et al. (2008), and engages computer vision methods for achieving tracking. Porter et al. (2010) use computer vision to detect the colour of the marker and track its position. Furthermore, feature-based tracking and model-based tracking are quite common methods. Wilson et al. (2010) use Kinect to track volumes in "LightSpace", and Harrison et al. (2011) achieved finger tracking with Kinect in "OmniTouch". Similarly to Kinect, depth sensing technology, such as 3D laser scanners, are also used to track changes in the environment. For an example, refer to (Mitasova, 2006).

In conventional augmented reality, we refer to head-mounted displays, desktop monitors, or handheld displays such as cell phone screens, as the enabling technology for display (Carmigniani, 2010). One factor that differentiates spatial augmented reality from traditional augmented reality is, in fact, the display technology. SAR's basic concept to render virtual objects directly within or on the user's physical space, makes the physical surface the display, which is achieved by digital light projection technology. Digital light projectors serve as the display devices, whereas the physical surfaces as the display surfaces (Raskar, 2001). Regarding display surfaces, the ideal surface is a light coloured diffuse object with smooth geometry. According to Raskar et al. (1998), it is practically impossible to render vivid images on highly specular, low reflective, dark surfaces. But nowadays, we can basically project the scene on any surfaces, even on a sandbox.

SAR systems depend strongly on the application they are designed to serve. SAR systems are reported to be used in a variety of museum fields. Tonn et al. (2008) developed a system that integrates architectural software with SAR-enabling software to facilitate interactive architectural scenarios of museums. Han et al. (2006) made use of projection technology to extend the interface of standard desktop applications into physical museum environments, aiming at visitor-entered related interaction. Moreover, a use case of the work of Bandyopadhyay et al. (2001) in Dynamic Shader Lamps was an exhibiting work called the drawing application. The application was informally tested by a kid, and the scenario fits educational purposes inside museum environment as well. Jones et al. (2010) demonstrated three examples of applications, namely a golf game, a tanks game and photo viewer, in which the link to entertainment is apparent. Wilson et al. (2010) focused on exploring a variety of interactions and strategies related to interactive displays and the space they inhabit, which can easily be applied to museum presentations. Finally, Mitasova et al. (2016) worked on real-time landscape model interaction using a tangible geospatial modelling environment. They aimed to achieve a more intuitive collaborative interaction with digital museum landscape data, which also might be useful for educational purposes and learning simulations and geological studies inside the museum.

Fig. 4.3.3: The design and application of augmented reality user interface for geospatial modelling for geological studies inside the museum. Images provided by Anna Petrášová, 2016

4.4 Re-conceptualisation of Augmented Space

With the advances of a wider community of users having access to the AR system analysed above, the author has a deeper understanding of the technological aspects of the AR world. In the meanwhile, those AR features provide instantaneous positioning and real-time, mixed reality information, digital mapping and user interactions are expanding, enabling enhanced immersive experiences in the physical environment. All disciplines are imagining and utilising these augmented features with specific subjective narratives for changing the original physical space. These narratives of the new augmented space are all interacting and intersecting in three key ways: firstly, bridging physical and digital space; secondly, mediating social and cultural changes; and finally transforming space to place, as described below.

4.4.1 Bridging physical and digital

The first feature of augmented space is bridging physical and digital space. With all the fundamental components of AR system, instead of showing information on separate screens or isolated interpretive device, augmented space puts all the digital data into the real physical environment, thereby blurs the real and virtual, and eventually combines them in a natural way.

The term 'Augmented Space' first defined by Lev Manovich in his article "The poetics of augmented space" (Manovich, 2006), this article was originally written in 2002, and revised for publication in 2006. It is interesting to note the differences between the original text and the updated version. The most noticeable difference is the addition of an introduction—what was once a somewhat disjointed investigation into the implications of augmented space, here Lev Manovich begins with a set of provocations and a definition of terms. He opens with a question: "How is our experience of a spatial form affected when the form is filled in with dynamic and rich multimedia information?" The introduction also includes a definition for "augmented space:" "augmented space is the physical space overlaid with dynamically changing information" (Manovich, 2006). A witness to the contemporary phenomena of media-saturated urban environments and the proliferation of small, portable computational devices, Manovich is interested in their effect on human perception and experience. How do we process these spaces? Is the underlying form secondary to the information being presented upon it? Do we intuitively combine the static spatial elements with the dynamic media layer into a perceptual gestalt or do they remain separate? Intriguingly, few changes were made to account for technological developments for the new text. Ultimately, this is not a piece on specific technologies but rather on phenomenology. Manovich is concerned with the effects these digitally-enhanced spaces have on the human condition. He argues that augmented space is a new paradigm with its own logics and implications, he places it within the larger historical context of ornamentation and augmentation of the human built environment. Therefore, as technology has advanced over the last decade, Manovich's astute observations remain as relevant as when they were written, if not more so.

According to Manovich, the critical distinction between virtual space and augmented space is that the former constructs an artificial spatial experience unrelated to its immediate environment whereas the latter creates layers of digital information over a "real" space. Qualifying the 1990s as a decade focused on the virtual, he suggests that the 2000s will be a decade all about the physical, albeit a sort of digitally-mediated physical. Manovich discusses the contemporary technological conditions that have made augmented space possible and even commonplace: video surveillance, cellspace[8] technologies (which he sets in opposition to surveillance, in that it delivers data to users rather than monitoring them), and digital displays (which take the invisible information of cellspace and makes it visible). All technology simultaneously augments and restrains, and he places surveillance and augmentation in a "symbiotic relationship," where tracking users can be both an improvement of experience and a form of control. Under a new section heading titled "Panopticon and Information Theory", Manovich continues to list the major fields of space-augmentation research and crafts an argument around these technologies as extending the model of the panopticon beyond geometry and visual sight lines to encompass data transfer, replacing the binary seen/not seen with a gradient of variable bandwidth. Manovich discusses the importance of scale in this context—our perception of "immersion" is subject to the scale of the technology relative to our bodies. In this sense, it is linked to spatial design practices already well understood by architects.

The connection between real time electronic data and the real physical environment was also highlighted by Thrift in 2004, he mentioned that "as a result of the intervention of software and new forms of address, these background time-spaces are changing their character, producing novel kinds of behaviours that would not have been possible before and new types of objects which presage more active environments" (Thrift, 2004). In another word, these novel kinds of behaviours are producing interactive narratives through electronic real-time data, and then making the physical environment more active, more immersive.

The real-time, active instantaneous positioning that have evolved these days by new technologies are demanding new grammars, allowing new forms of interaction, as well as the dislocation of the original

[8] According to writer David S. Bennahum, cellspace is the kind of cyberspace you experience when equipped with a cellular telephone that can be connected to the Internet.

boundaries. These Augmented Spaces that are producing these active physical environments are similar to Christian Nold in the thesis - Emotional Cartography - Technologies of the Self, which claims the new augmented space as an egocentric subjective environment (Nold, 2009), where according to Grau (2003) it is possible to physically "entre it". Grau mentioned "the panoramic view is joined by sensorimotor exploration of an image space that gives the impression of a 'living' environment, interactive media have changed our idea of the image into one of a multisensory interactive space". The parameters of time and space can be modified as will, allowing the space to be used for digital modelling and multimedia experiment. It suggests the possibility that we can immerse ourselves in the environment with augmented space over-layered and move and interact in real time to determine which narratives to activate and engage with.

4.4.2 Mediating social and cultural changes

The second feature of augmented space is its ability of mediating social and cultural changes, as Manovich described this dynamic between architecture and information as the space of augmentation. In augmented space, data is overlaid onto physical space. In such electronic landscapes, the mobility of media is utilised to its full capacity. This type of this media convergence has permanently changed cultural morphology, social relations and public communications.

For that reason, augmented space also changes the socio-cultural experience of a built environment by placing the individuals inside the total environment and let them explore by their initiative (Manovich, 2006). With the later publication - the poetics of urban media surfaces, he further proceeded to discuss the white cube (the gallery) vs. the black box (the cinema) as zones of social-culture experimentation around the concept of augmented space (Manovich, 2006). Moreover, Manovich initially sets up a dichotomy between the two by describing the white box as dynamic, allowing for more radical experimentation and iteration, whilst the black box as more static, because the form of cinema is dependent on fixed technologies like the traditional projector. With sensing, tracking and registration system, new augmented space like the white cube allows people to reform their relationship actively with environment and objects surrounding, such as one to many communications enable the shared spectacle, as well as through its interactive capability to let the general public respond to the setting, and capture their views immediately.

Moreover, the evolution and expansion of augmented space with HCI (Human-Computer Interaction); CSCW (Computer Supported Cooperative Work) and more interaction design shows that the discipline's focus has shifted from the interaction episodes occurring between an individual user and the computer system, to the more complex domain of user interaction with the physical setting and technology within a rich social, cultural environment. Especially in the dimensions of the 'collaboration' and group use of technology, and the dimension of social interaction around the use of collaborative systems (Bannon, 1992). Weiser in 1993 also mentioned that, these innovative augmented technologies pose new challenges for Interaction Design, and the focus has shifted from the human-machine relationship to more complex scenarios of social interaction with distributed technologies (Weiser, 1993).

4.4.3 Transforming 'space' to 'place'

The third feature of augmented space is connecting the concept of space and place. Traditionally space refers to abstract location and geometrical extension, while place describes the experience of being and investing a physical setting with feeling, meaning and even memories.

German philosopher Otto Friedrich Bollnow articulated his work around the concept of "lived-space" as the place (Bollnow, 1963). He suggested an "anthropological" concept of space as the one that would include aspects of human experience in the study of the physical environment (Bollnow, 1967), as Egenter mentioned in the thesis:

> "Space was not there from the beginning, as we assume with the Euclidian concept. Space in the human sense has evolved. As a concept related to human perception and culture, it was originally closely related to dwelling and settlement and subsequently developed by extension of the spatial perception of man"

Bollnow, 1967; cited by Egenter, 1996.

Maurice Merleau-Ponty (1945) was the first to introduce the concept of "Anthropological Space". Anthropological space is inherently opposite to "geometrical space": anthropological space is irreducible solely to physicality, and transcends its structural dimensions to encompass human activity as the constituent of the identity of the space itself. He notes: The "anthropological" vision of space is a common trait of phenomenological approaches (notably, Merleau-Ponty, 1945). The meaning of space here is dynamically related to the perception of it by humans and to cultural influences: the boundaries of space as an entity and a concept change according to human experiences within it. Mainly, movement and the possibility of movement together redefine space. Merleau-Ponty's work has also had a strong influence on contemporary authors: a notable example being Marc Augé. Augé proposes a similar vision of space (referring directly to Merleau-Ponty) in his notion of "anthropological place" (Augé, 1995). If we stop considering the space as a mere shell, a container, or a location, and start looking at it as a setting for action, experiences, communication, then effective enquiry concerning human actions and activity can take place.

A common feature to all these perspectives, is the consideration of the structure and geometric disposition as the primary attributes of space, but not necessarily the only ones. Even geometrical disposition depends on human interpretation, practice and experience, as we have discussed above, all recognise the importance of associating experience, practice and meaning to the structure of space and its features. Philosophers as Bollnow focus more on individual memories and emotions that may be invested in a space, while Phenomenologists such as Merleau-Ponty and Marc Augé focus more on the embodied nature of experience.

In term of the world ‘place’, as mentioned, place has an existential significance as it is an entity with “incarnate the experience and aspirations of people” (Tuan, 1971 & 1975). Munro, Höök and Benyon (1999) discuss the concept of place from different angles, particularly regarding how the use of the notion of place and its role in architectural theory can inform the design of information spaces. For Munro, it is behaviour that creates a place. Thus, we need to look at how different communities use the same space in different ways, or, in making different places (Munro, 2000). Similarly, Crabtree (2000) applies a sociological perspective in understanding the relationship between these two terms - space and place, according to him, the relationship between space and technology is a practiced one, in other words behaviour is what shapes place. From yet another perspective, Turner and Turner (2003) propose phenomenology as the perspective from which to conduct studies of place, in order to inform the design of realistic virtual models of actual locations.

Chalmers (2001) outlines an approach to space and place inspired by post-structuralistic semiology. For Chalmers, symbolic interpretation through the language of space and media that populate it is what makes of a space a place. He aims to extend Harrison and Dourish's vision through a semiologic approach concerned with how interpretation shapes our actions within a space, physical or virtual. According to this perspective, the symbolic nature of our interaction with the space explains how language supports navigation within "space-less places" such as a virtual world. This approach, although interesting, presents issues for critique as it over-emphasises the analysis of linguistic representations of place over the more physical and embodied aspects of people's experience of place. Many qualities of place are identified and discussed in the geographical literature. A complex 'picture' of what constitutes place is presented to us: actions and activities, meanings and interpretations, physical features, lived experience by individuals and social groups, cultural elements are all identified as fundamental elements of place-making.

This review of philosophical theories of space and place provides useful insights for understanding augmented space: the emergence of notions of "augmented space as experienced space" is apparent within the phenomenological school. Also, bodily presence and perception are considered as essential factors of human experience. And, unlike virtual space, the making of augmented space will be based on the original physical form, and locale, as a metaphor for the design of augmented reality system, will further support social collaboration and communication (Muller and Friedman, 2000). Different concepts that underpinned spatial study in the past are now called into question by new spatial relations directly influenced by new technological, social and cultural paradigms. With augmented reality technologies, the spaces we inhabit can be easily modified; new places or new forms of presence is created, to make physical presence itself a way of interacting with the system (Ciolfi, 2004). In another word, augmented space encompasses the relationship between physical space and human experience, social practice and activities, the concept of space and place are eventually roll up into one.

4.5 Chapter Conclusion

This chapter explored the relationship between AR technologies and Augmented Space, which started with the brief history of Augmented Reality. The term of "augmented reality (AR)" was officially coined in the year of 1992. Then 10 years later, the idea of "augmented space" was first defined by Lev Manovich in his article "The poetics of augmented space", which is "the physical space overlaid with dynamically changing information" (Manovich, 2005). After Manovich, several researchers tried to develop the concept of "augmented space" from different perspectives, as Grau (2003) describes it as "the highly immersive narrative which connect[ing] the human senses to the image world". While in Thrift's theory, it is described as a 'qualculative sense', which is a result of "the intervention of software" and "new forms of address", these background time-spaces are continuously changing their characters, producing novel kinds of behaviours that would not have been possible before and new types of objects which presage more active environments (Thrift, 2004). Similar to Nold & Boyd-Davis' (2009), who describe these active physical spaces as the new egocentric subjective environment. With the aim to characterise and re-conceptualise the idea of "augmented space", this chapter provided a detailed study of the SAR system, after illustrates the background of augmented reality. It moved to four fundamental components which includes 1) display system; 2) sensing, tracking and registration; 3) input and interaction techniques and 4) virtual content creation and rendering.

The features of those AR systems, as the use of a projector as a display device affords the possibility of illuminating physical objects with complex 3D geometry, also with IO (Input and Output) elements to bridges physical with digital space. For users in that space, the narratives that are evolving from these AR features are becoming limitless for them, augmented spaces are continuously connected to the internet wirelessly and as mentioned, users are provided with real time data in any location in which they are situated. By placing the individuals inside the entire environment and let them explore by their initiative, augmented space also changes the socio-cultural experience of the original architecture or built environment. The complex 'picture' of augmented space is presented in actions and activities, meanings and interpretations, physical features, lived experience by individuals and social groups and even cultural elements, all of them can be identified as fundamental elements of place-making. In another word, augmented is transforming 'space' to 'place'. From the literature review, social and cultural theorists also remind us that 'place' is not only about its location, spatial infrastructure and physical characteristics, but more so socially produced (Tuan, 1977; Certeau & Rendall, 1984; Lefebvre, 1991; Gordon & de Souza e Silva, 2011).

With the development of augmented technologies, gallery or museum designers increasingly draw on the diverse insights of sociology, developmental psychology and educational theories to ensure that the new interactive galleries proven to be educational as well as entertaining. The next chapter will focus on museum learning theories, analyse the different approach of embedding augmented space for learning in museums.

Chapter 5.

Augmenting Space for Museum Learning

Figure: Martin Seck and Tony Lee. (2013). Photograph. MoMA Art Lab: People.

Chapter 5. Augmenting Space for Museum Learning

5.1 Chapter Overview

This chapter presents an attempt to grasp the complexity and what is distinctive with the contextual model of learning in the museum environment with different ways of augmenting museum space. The first part of the chapter focuses on learning theories, museum learning and museum educational practice has their own positions in the educational field, especially for scientific exhibitions inside museums. It draws special attention on learning in relation to experiences with interactive installations and objects in the socio-cultural context, and further elaborates on how constructivist approach is positioned in the educational field of interactive learning in museums.

Interpretive devices like audio and multimedia guides are effective additions inside the museum environment, and each of the profiled technologies has a significant relevance to museum education and interpretation. However, there’s criticism that audio and multimedia devices detract visitors from experiencing the real exhibits and their physical surrounding and further decrease their social experiences. It is a characteristic shared to a greater or lesser extent by all interpretive devices. Augmented space, on the contrary, is well aligned with nowadays constructive learning notions in the museum field, as each visitor is able to control their individual learning process and manipulate content that is not real in an augmented physical environment to derive and acquire understanding and knowledge. Using augmented space to replace interpretive guides in museums means the museum experience is moving from didactic or instructive to active or discovery learning. The new augmented space in the museum is promoting visitors with self-explorations and the embodied experience build up a strong link between the visitors, exhibits and space. In another word, the augmented space provides museum environment brand new digital storytelling and next-generation edutainment tools

5.2 Models for Museum Learning

Learning in the museum has historically always been on the agenda of museum studies and museology, but after half a century without the primary focus on this, it is yet again on the agenda (Hein, 1998). Additionally, lately museum education discussions focus on John Dewey and his theory of education and experience and his argument that a museum is a good example of how a school should be. "The Museum can have a profound impact on children's motivation an interest in learning to create the kind of present experience that lives fruitfully and creatively in subsequent experiences" (Dewey, 1963; ref. in Hall and Bannon, 2005). This is why museums have an important role in children's education, where they have opportunities to gain a deeper understanding and interest in the material culture and the history that it represents (Hall & Bannon, 2005).

Learning space associating with school spaces and formal classroom environment are likely to have formal educational programs are typically synonymous with strict, full-scale learning management systems, with curricula or courses mapped in a structured way (Cournoyer, 2012). However, an increasing number of research papers show that the "softening" classroom space and add informal learning programs will have a positive impact on student learning outcome comparing with stereotyped school environment (Gifford, 2002). The informality ensures interaction and increases participation; provides a lot more flexibility in the way content is both created and consumed. It is helpful to keep students focused and promotes deep discussion at the same time.

Museum spaces are the opposite of the formal classroom learning space, which provides free-choice and active environment to the visitors. The total informal learning approach will spark the intrinsic motivation and interest of those museum visitors in new pedagogical approaches. However, since the museum is a place of informal learning, it occurs completely voluntary – visitors generally come without distinct learning goals, and that there is no test of knowledge at the end of the exhibition. There seems to be a certain discrepancy between what museums and museum visitor consider to be learning. For visitors learning is distinct from formal education, according to Megan Axelson, a researcher in the field of museology: "In 'learning, visitors gain an understanding through self-discovery, whereas in 'education' visitors are instructed in skills and information." (Axelsen, 2006) For museums, learning is often synonymous with education. Hence almost all museums have the department of education. Doering even goes as far as saying that most museums use the "baby bird" model when it comes to education. The incidents show that the visitor is seen as having a relatively undeveloped appetite needing the wise and learned feeding of a museum (Doering 1999).

Another interesting fact is that even though museums and museum visitors think learning is crucial for their museum experiences, most museum visitors, even with interpretive devices, acquire little new factual knowledge (Doering, 1999). This suggests that museums are not very successful at educating their visitors. It is therefore important to find out how museum visitors learn and what museums can be done to stimulate an effective way of learning. Kirsten Gibbs, et al. in their book about lifelong learning in museums say that there are four theoretical approaches to learning in museums: the instructive or didactic approach, the active or discovery learning approach, the constructivist approach and the social constructivist approach (Gibbs, 2007).

The instructive or didactic approach in museum space will appear as sequential exhibition line with an intended order, for example, a clear timeline from beginning to the end, or a hierarchical arrangement of the subject from simple to complex. The instructive or didactic approaches also follow a traditional curriculum and help those educational programs with specified learning objectives, visitors can easily find those didactic components such as images, panels, labels and audio contents that describe what is to be learned from the exhibition (Hein, 1998). The concept of active learning, by contrast, has several aspects, including, experienced-based learning; actively engaging in meaningful activities in the real world; collaboration, taking part by talking about what is being learned, and making it an active interaction (Chickering & Gamson, 1987).

Traditionally the main focus in museum communication is on the subject, i.e. what is to be learned, has been the main focus, but contemporary museum scholars have twisted this view and today concentrate more on how we learn and the process of learning in museums. In this way, Hein suggests a constructivist and social constructivist view of learning, where attitudes and perceptions about how one is a "good" museum visitor in a particular class or group, also have a decisive influence on the response of an exhibition (Hein, 1998). The museum’s interest in learning is also motivated by survival and a legitimisation of museums role in society (Hein, 1998). Recent years a strong interest in visitor participation in museum communication has followed the introduction of digital technologies and social media. The Museum's desire to promote participation has the same origin that other organisation that is concerned with learning, education, and youth development, such as schools and after school programs. "The prime focus being on young people's building of positive identities, on the democratic access and commitment to learning as well as on participation in decision making" (Stuedahl & Smordal, 2011a). James V. Wertsch (Wertsch, 2002) argues that the key issue in the field of museum learning is related to what outcomes we should hope for after a museum visit. Even to make the slightest analysis of development there must be present an idea on what this development leads to, that it must be established a plan ends (Wertsch, 1998). This grounding is essential, in order to decide how to do further research in this field, as well as in order to understand and develop museum educational perspectives further. This, he says, brings us to the fundamental question about the development of motivation, learning, and identity in children which traditionally are based on research in formal education (Wertsch, 2002), thus the need for further research on these issues within the field of museum learning.

According to Falk and Dierking's research (2000), the richness and complexity of learning from objects and experiences are not yet fully included in the traditional theories and models of learning. Learning and experience from objects have a special contextual nature that it is important to take into account. The role of the context is such an essential ingredient missing in the facilitation of learning from objects and experience. "Much of the educational research has focused on learning in the classroom and in labs where there has been a de-contextualisation from direct experience with object" (Dierking, 2002). This is based on a perception that there is an inherent physical and socio-cultural nature in the experience related to objects, which has an extensive potential to have an essential consequence for learning, and these processes include much more than just the learning of facts and concepts. These include changes in attitudes, beliefs, aesthetic awareness, identity, etc., something Dierking (2002) believes is missing in the traditional research of learning.

There are distinct aspects related to the museum experience (Falk, 2002). The experience and learning related to physical objects and representations are directly related to context and what it represents for the viewer. And visitor's prior knowledge and experiences frame the meaning making from interactions with objects during a museum visit. Material objects represent more than just one reality and the museum is therefore, an institution which may facilitate for placing these objects in a social and cultural context. Hence, the museum experience must be seen as something larger than the museum itself (Falk, 2002). If the visitor's experiences related to the museum objects are present, the process of meaning making during the museum visit take on totally different directions than if absent. This issue is handled in the Contextual Model of Learning which is presented in the next paragraph.

5.2.1 Contextual model of learning

Museum learning can be conceptualised as the integration of three overlapping contexts as shown in **Figure 5.2.1-1**, being personal, physical and socio-cultural context.

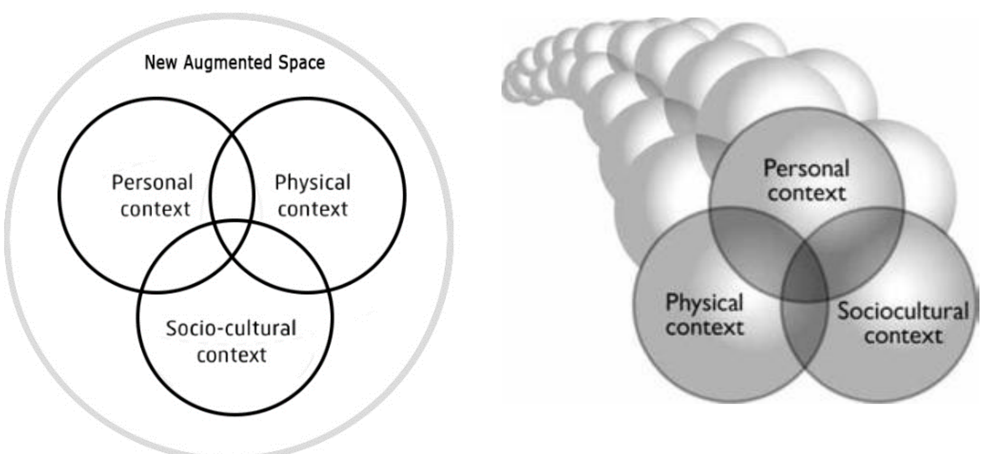


Fig. 5.2.1-1: Left: Museum Contextual Model: The contextual model of museum learning consists of three different contexts naming: Personal Context, Physical Context, and Socio-Cultural Context. Right: Museum learning is a never-ending process, it is more like a cumulative process that requires all museum designers and educators to design their educational interventions in ways that build upon prior experiences and lead to subsequent experiences.

Source: Falk and Dierking 2000

Falk and Dierking (2000) present in their work a frame for understanding museum learning as subjective and tightly bound to the individual's previous knowledge, experience, interests and context. Based on investigations and studies of learning in museums, science centers, and botanical gardens they have developed a model of museum learning that defines it as related to the personal, social and physical context, proving that in the field of museum learning, there has been a shift from a focus on what is learned to how we learn (Falk and Dierking, 2000, Hein, 1998). And they developed a model to deal with the complexity and scope of learning and meaning making from objects and experience.

> The Contextual model of learning – starts from the premise that all learning is situated, a dialogue between the individual and his or her environment. It is not some abstract experience that can be isolated in a test tube or laboratory, but an organic, integrated experience that happens in the real world with real objects. In other words, learning is a contextually driven effort to find meaning in the real world. The model advocates thinking more holistically about learning as a series of related and overlapping processes that accommodate the complexity and ephemeral nature of learning and meaning-making from objects and experiences, learning that we call free-choice learning
>
> (Dierking, 2002)

This approach to museum learning is based on using the concept free-choice learning instead of informal learning because it describes learning from objects and experiences better than to describe it as what it is not (formal education) or where learning is happening (Dierking, 2002). Free-choice refers to the open-ended facilities in a museum where the visitors can move freely in the exhibition spaces, and create meaningful and personal experiences. However, the learning outcome of a free-choice visit to the museum has been discussed. The Contextual Model of Learning suggests that three overlapping contexts contributes and influences the interaction and experiences children and young people have with the artefacts and the subsequent learning and meaning making. These three are: the personal context, the socio-cultural context, and the physical context. The interaction between these contexts is the process/product which leads to learning. Dierking argues that the Contextual Model of Learning is more descriptive than predictive. The personal context: the learning individual brings with them their interests, motivations, their preferences for learning and previous experience and knowledge. The socio-cultural context: recognises that learning is both an individual and a group experience/experience. The learner is inextricably attached to the cultural and social context where the learning occurred. The physical context: bring into question that learning does not occur in isolation from the artefacts and the experiences from the real world. This includes the structure and the anticipation of the circumstances and the sights, sounds, smells, and design features of the experience. In addition to these three dimensions, time is an important factor. Learning is constructed over time were people move through their socio-cultural and physical surroundings where meaning is being built up layer upon layer (Falk and Dierking, 2000).

5.2.2 Free-choice learning

Traditionally in the museum field, studies of student learning are based on surveys that too often emphases on the implementation of the program in question and leaves the study of the visitors' outcome open (Froyland, 2010). "It seems that museum educators forget the student's experiences and their learning outcomes because they are busy occupied meeting the schools needs and the requirements of the curriculum" (Froyland, 2010). It has been questioned whether anything at all is being learned in the museum but Falk and Dierkings (2000) research demonstrate otherwise. Even if the visitor does not necessarily learn what the educators or the developers would have predicted, their research shows that the museum experience to some extent facilitates learning for all the participants. The visitors were expected to increase general awareness and interest, but what was learned is highly personal and unique. Yet, what specifically is learned depends on the person's unique personal socio-cultural background, and therefore will vary from individual to individual. The visitors bring their past experiences, interests and their own socio-cultural identity into the museum experience. Since learning is always influenced by the physical context, Falk and Dierking argue for a focus on the design of the exhibits and the design of educational programs of museums as having an impact on what the visitors are learning (Falk & Dierking, 2000, Paris, 2002).

Anne Kahr-Hojland (2010) developed a project for using mobile phones on an existing exhibition in a Science Centre. It illustrates an increasing focus on educational methods and innovative learning resources (Hojland, 2010), and Hojland's educational tool was developed as a participatory tool to support student's scientific competence and to encourage interest. Using the visitor's own cell phone, they created a narrative layer as a personification of the experience of an existing show in a Science Centre. Hojland distinguishes between participatory design and design for participation. The first aiming for visitor involvement in the innovation of the process, and the other to innovate the product to be participatory (Stephenson et al., ref. in Simon, Nina, 2010). Participatory designs consolidate well with the arguments about learning, participation, and a digital world, and minds-on approaches in the museum. Hojland presents a digital narrative for Augmented Reality (AR) – a digital extension of the physical environment which is determined by the physical context - "The personal exhibition". She refers to Oppenheimer (1968) who had the idea that a Science Centre should be like a forest of phenomena, focusing on free interaction. Hojland says that from an educational point of view, this apparent lack of structure and a high degree of freedom make the visitors feel overwhelmed and inadequate (Hojland, 2010).

This issue is also put forward by Jeffrey K. Smith and Pablo P. L. Tinio (2008). Their findings suggest that the visitor requires a mix between structure and freedom. With Hojland's project's semi-closed structure of a participatory design (innovation the process) the representation/narrative lowered the experience of chaos and inadequacy, as visitors often experience in an open "free choice"-based exhibition. Hojland believes that their choice of technology has an origin in the potential of mobile phones to create a structure and a meaningful experience for young people in a Science Centre. With this technology, one can produce a digital narrative that supports both individual and social learning processes (Hojland, 2010).

Free-choice learning has proven to have the potential to inhibit learning. If a learning context is characterised by total freedom and lack of structure it is likely to be overwhelming and chaotic. Prominent writers and researchers in the field of museum research argue that digital media has a high potential to counter this overwhelming chaos (Tallon & Walker, 2008, Bamberger & Tal, 2007). Digital media is therefore used as it has a potential to create a new learning ecology which may improve visitor interaction in the museum in connection to their personal context, socio-cultural and physical context, this in an attempt to enhance deeper understanding and more complex learning (Bamberger & Tal, 2007).

In a comprehensive study, Bamberger and Tal (2007) studied about 750 students on class visits in four science and natural history museums in Israel. They utilised Falk & Dierking's (2000) contextual model of learning as their framework for learning in the museum, however they mainly focus on the personal context of learning. They too bring to the discussion the issue of free-choice learning. The primary objective of this research was to focus on the level and types of choice which the students encountered during their school visit, and furthermore how different types of choices affect learning (2007). Their research identified various levels of choice: no choice, limited choice, and free choice. Activities that provide limited choice were identified as the option which best comprehends the qualities of complex and more effective learning.

In the extension of this study Bamberger and Tal (2007) have set up following items for a museum visit to be meaningful for students: 1. the students should be offered concrete task or activities that can only be implemented at the museum. 2. Task and activities should only be solved in collaboration with other students. 3. The lessons at the museum should be in close relationship with school education. In an educational program in the museum without choice or without free choice, the link between experiences and observations are absent, and a limited choice program has proven to maintain this dimension (Froyland, 2010).

5.2.3 Constructivist learning

This subsection focusses on the literature of socio-cultural perspective on museum learning, communication and knowledge building, which leads onto the core in a socio-cultural perspective in learning and production of knowledge. As we thrive, live, learn and develop accordantly to the cultural background we are a part of the system. Hence, acknowledgement, development and learning do not exist disconnected from our cultural affiliation. Knowledge and meaning making is closely connected to the cultural and semantic recourses that the context provides, and we learn within the framework of interpretations and way of thinking which these recourses facilitate (Saljo, 2001). Knowledge is related to cultural development evolved from hundreds of years of human activity, and other historical influences provide us with a diversity of choices. The question evolves around whether human development is internally or externally influenced (Imsen, 2005).

However, the different traditions of learning theories, most certainly practically emerge and a definitive empirical divide between them is uncertain. The behaviourist theories are positioned in an assumption that knowledge is somehow more or less objective and something to be discovered (Imsen, 2005). In learning and education, the focus is then on external stimuli as the cornerstone in human learning and development. Another direction in this regard is behaviourism's counterpart, constructivism. Constructivist theories emphasise that knowledge only exists in the human mind and consequently not something objective to enquire and memorise.

These ontological and epistemological discussions illustrate perhaps the impossible mission to identify a clear and ubiquitous definition of learning. Roger Saljo (2001) argues that the essential challenge for the socio-cultural view has to do with integrating physical and physiological tools (I.e. artefacts or cultural tools) into the understanding of human learning and thinking. If to understand the interaction with artefacts and other people we must not fall under a reductionism where we understand thinking and learning as only what takes place in the mind of individuals. Therefore, the need for exploring human interaction with cultural tools as part of their meaning making process (which is the objective of this thesis). Furthermore, what implication this view has for what knowledge and skills which are essential to be learned in school and education.

If we remove psychological and physical tools and social practice in the study of human learning and thinking he argues that: "then we are studying helpless individuals who are deprived of their socio-cultural resources" (Saljo, 2001). One person properties are limited, it is the collective nature of human that define our qualities. We build knowledge into artefacts and so development is always an extension of the previous. Consequently, her claim is that a direct subjective relation to our surroundings is not possible. We mediate with intellectual and physical tools integrated in social practice, hence, our perspective on these issues is illustrated in our pedagogical practice. Today, learning is seen as an active participation by the learner with the environment, which relates to the overall discussion if knowledge is objective or subjective constructed (Saljo, 2001, Imsen, 2005,).

The constructivist approach in museums is promoting self-exploration and build up the link between the exhibit and visitor themselves is rewarding. This construction of knowledge is based on an interaction between subject and object, through perpetual exchanges of thought and different kinds of experimental interaction (Piaget, cited in Holzer, 1998). Within the museum environment, scientific exhibits can be regarded as facilitators to the construction of meanings about and within sciences and cultures (Falk & Dierking, 2000). Exhibits are seen to evoke memories and prior knowledge, and (Hooper-Greenhill, 1999a) sees the active mental construction of knowledge as a dialogue between observation and deduction. At the same time, the museum world in recent years has begun to accept that general visitors are not a passive, homogeneous mass of people anymore, but more likely to be seen as individuals with their particular interest, expectations, demands, preferred learning styles and social and cultural agendas. The former passive public visitor has been gradually treated as 'active audience' as it is mentioned by Eilean Hooper-Greenhill, it is essential for museum educationalists to begin to conceptualise the active method through learning theory and, especially, constructivism.

In accordance with the constructivist approach, rather than just using observation, this deduction comes most natural to people through active engagement, which can be facilitated by an interactive exhibit. The following definition of 'interactive exhibits' is used "those in which visitors can conduct activities, gather evidence, select options, form conclusions, test skills, provide input, and actually alter a situation based on input" (McLean, 1993). Interactivity in relation to an exhibit means that when visitors act on the exhibit, the exhibit will react on the visitor which is a ubiquitous element in contemporary science and children's museums (Allen & Gutwill, 2004). Aside from effectively conveying certain knowledge or understanding, interactive exhibits have also proven to be memorable, with many visitors being able to describe the thoughts and feelings they had at the exhibits over six months after their visit (Stevenson, 1991). To enhance this effect of memorability it has been suggested that an ideal learning experience with exhibits includes ways of capturing the experience since later reflection being able to access additional material that is providing a context for the exhibit. This extends the interaction with the exhibit beyond simple observation and direct physical manipulation (Spasojevic & Kindberg, 2001).

On the other hand, going to the museum is often seen as a social experience. According to Stephen Weil, an experienced scholar at the Smithsonian, people come to museums first and foremost for social reasons. Some of these reasons are spending quality time with family members, going on a date, or to hang out with friends. The museum experience is therefore often also a social experience. For some people, the interaction with others is even the most satisfying part of their museum experience.

With the aim to embed the social interactivity in the museum environment, more and more researchers found that augmented reality is well aligned with nowadays socially constructive learning notions in the museum field, as each visitor are able to control their learning process through the interactions with the real and virtual environments (Wang, 2012). As well as manipulate contents that are not real in an augmented environment to derive and acquire understanding and knowledge. When curators embed those augmented reality features into the physical space, the original environment can be as diverse and rich as human imagination can be. On the other hand, instead of showing information on separate screens or isolated interpretive device, augmented technologies put all the data right where it belongs: into the real environment, AR thereby blurs the real world and the user interface and combines them in a natural way, stimulating discussions, performing shared activities or creating a shared understanding with others could therefore enhance the museum experience.

5.3 Replacing Guilds with Augmented Space

As the author mentioned, the learning theory reveals the phenomenon that the more one knows about the story or scientific context behind an object, the more one is going to pay attention to it. The reason is simple, as there is already a greater framework of knowledge to build on. Doering's conclusion is that exhibitions are both inefficient and ineffective methods for communicating new information or changing attitudes, while recognising that they are powerful tools for confirming, reinforcing and extending existing beliefs. The key to learning is therefore the existing knowledge construction or as Doerings calls it the entrance narrative of the visitor. Knowledge of this entrance narrative could provide museums with the means to personalise visitor learning, as constructivist learning usually begins with a question, a case, or a problem (Cooperstein & Weidinger, 2004); with new learning builds on prior knowledge; learner construct their own meaning, which developed through 'authentic' tasks; and enhanced by social interaction (Good & Brophy, 1994).

From earlier research, the author noticed that augmented space is well aligned with nowadays constructive learning notions in the museum field, as each visitor able to control their own learning process and manipulate content to derive and acquire their own understanding and knowledge. Using augmented space to replace interpretive guides in museums means the museum experience is moving from didactic or instructive to active or discovery learning.

It also promotes a self-exploration journey and builds up the link between the exhibit, environment and visitor themselves which is always rewarding, as Deering's argument: "most satisfying exhibitions for visitors are those that resonate with their experience and provide new information in ways that confirm and enrich their own view of the world" (Doering, 1999). This construction of knowledge is based on an interaction between subject and object, through perpetual exchanges of thought and different kinds of experimental interaction (Piaget, cited in Holzer, 1998). The following subsection focused on different features between interpretive devices for museum space and augmenting the space using spatial AR technologies. Those augmenting methods for the museum space and exhibitions act as new genres of museum communication, and fundamentally changed the learning landscape of the original physical space.

5.3.1 Interpretive guilds

A lot of museums still seem to assume that exhibits in museum speak for themselves and therefore do not require interpretation. However, there is no guarantee that each visitor will understand what the object/exhibit is saying. Even museums that do not explicitly subscribe to this maxim often do act accordingly, providing little or no information about the scientific object in their collection. They leave it up to the visitors to make their own interpretations. This does not necessarily have to be a bad thing, but it does leave a lot of work for the visitors. Peter Samis, Associate Curator at the San Francisco Museum of Modern Art, gives a good description of what interpretation should do: 'The work of interpretation is to give cognitive hooks to the hookless, and assure that these hooks are sufficiently varied so that they can successfully land in the mental fabric of a broad array of visitors. Once visitors have a framework, all kinds of sensory impressions, emotions and reflections can weave themselves into the fabric of perception. In fact, the more you know about a subject, the more you can learn about it.' (Samis, 2007) In other words, it should try to make each object more accessible and relatable. Interpretive devices are the devices that are used to provide this interpretation.

Fig. 5.3.1-1: Audio Guide (Left) vs Multimedia Guild (Right)

Source: British Museum, 2016

Nowadays Museums use a broad range of interpretive devices like digital wall labels and audio tours. Most of which have been around for some time. The digital audio and multimedia guides are relatively recent additions. Each museum makes its own mix of interpretive devices to offers to its visitors. The following two sections will only focus on audio and multimedia guides, providing an overview of interpretive devices inside museums.

Audio guides

One of the first audio guide systems was developed in the 1950's, it was called Ambulatory Lectures. The system used short-wave radio broadcasting to distribute its content. It broadcasted lectures in different languages to visitors that had a radio receiver. These lectures were recorded on a tape and then played sequentially, meaning that all visitors heard the same lecture at the same time in the same language. In the 1970's a Walkman taped tour was introduced and in the 1990's the transition was made towards digital technologies. Nowadays, all audio guides are digital. Digital audio guides enabled the development of non-linear audio tours. This meant that visitors became free to choose whatever story they wanted to hear, at any given time, thus giving the visitor more control and freedom. However, it has also made it more difficult to tell a story that connects works within an exhibition, because it is hard to know what content the visitor has previously heard. A consequence is that nowadays each work has its own separate story. This can be somewhat avoided by adding a general story to each exhibition room, a story that is not linked to a single work.

Most digital audio guides feature a keypad that enables visitors to type in the number of the object that they want to know more about, to trigger the content. This number suggests a certain sequence; this can either be positive or negative depending on whether that sequence really exists. Wi-Fi and infrared are other ways to trigger content. Most audio tours only have one level of interpretation; however, some tours have an option to request more information. This is usually announced in the audio content itself and requires you to type in another number. Audio guides provide feedback through audio and often also via a LED display.

Throughout its history the audio guide has been the subject of a lot of criticism. One early comment is: 'It is a fact beyond doubt that a great many visitors like to wander at will, stand and stare, and equally dislike any breath of regimentation. There is a danger that with the wide application of mechanical gadgets the quality of visitors may suffer (Tallon, 2008). Some of the concerns expressed above are valid, research has shown that the audio guide not only influences the behaviour of the people who use them but also of those who do not use them. A positive behaviour change is that visitors with an audio guide tend to spend more time in the museum. This is caused by the fact that they tend to stay longer at an object, even if it is only to listen to the entire audio stop. In addition, an audio tour keeps the visitor's attention focused on the object itself instead of diverting attention to for instance the label. An effect that is more questionable is that visitors tend to go mostly to objects that have audio content; they will perceive these works as being the highlights of the exhibition or museum. Furthermore, it appears that an audio stop clearly directs attention towards the aspects it covers, and away from those that it does not cover.

Research has shown that the main reasons for visitors not to use an audio guide are that they have never tried one before or the costs. Another often heard complain, is that the headphones of an audio guide inhibit conversation among visitors. However, research has shown that few visitors see this as a reason for not taking an audio tour (Smith, 2008). This either means that people do not miss this conversation or that the audio guide is no inhibition to it. It does, however, tend to send a certain signal to other museum visitors about not wanting to be disturbed and/or about not wanting to participate in a general conversation. Some solutions have been proposed to address this problem. Instead of using a headphone one can use a single earpiece or a wand type audio guide.

Audio guides are already widely available in museums. A recent survey shows that more than 50% of museums have an audio tour. (Wetterlund, 2003) Of the museums offering an audio tour about 50% has included them in the ticket price, giving them to all visitors. (Proctor, 2003) One can say that audio guides are perceived to be capable of enhancing the museum experience.

Multimedia guides

Multimedia guides are often seen as the next step in the development of interpretive devices, a more sophisticated version of the audio guide. Most audio tour companies have therefore also developed multimedia guides. The main difference between an audio and a multimedia guide is the screen. A large colour screen and usually also a touch screen interface characterise the multimedia guide. Content can be triggered in the same way as with audio guides. The content of multimedia guides tends to have multiple levels that can be accessed through a menu visible on the screen.

The greatest advantage of multimedia guides is that they are able to provide the visitor with different media including text, images and videos. It is rather obvious that multimedia tours offer museums the opportunity to provide greater access to intellectual and cultural resources. The multimedia guide also appeals to new audiences like visitors with hearing impairments, younger people and school groups. Audiences that are more difficult to reach with traditional interpretive devices, and at the same time, audio guides and multimedia guides also influence the behaviour of its users. Research tends to show that people spent a lot of time looking at and operating the device. Some even suggest that visitors look more at their multimedia guide than at the actual objects. (Vom Lehn, 2003) In contrast to audio guides the screen of the multimedia guide can be seen as a distraction, for this reason, they are probably even more isolating than audio guides.

However, although the research on multimedia guides is scarce, the overall results are still encouraging. The research seems to show that people using multimedia guides have more extensive learning experiences, demonstrate a deeper level of understanding and critical thinking, make more connections to their own history and background and engage in greater personal learning in all kinds of museums. Museum professionals are also able to use the logs of visitors' actions to get more meaningful information about the attracting and holding power of exposed objects as well as about the way the multimedia resources are used. (Damala, Marchal & Houlier, 2007) Despite the fact that evaluation has proved to make the application to be effective (Damala and Kockelcorn, 2006), some specific issues about multimedia guides demand further attention:

1. The interaction surface of multimedia guilds is usually small and so selecting and manipulating objects might prove to be a difficult task especially for the elder or for visitors not acquainted with the interface.
2. Geo-localisation is a very helpful feature for visitors, but it often proves to be not enough as it is not always easy for visitors to use floor plans of the exhibition space. In that case knowing the direction towards which the visitor is looking could be extremely helpful.
3. The threshold to introduce a multimedia guide system in a museum is higher compared to audio guides. Not only for more expensive hardware, creating new contents is also going to be relatively time-consuming and expensive.

4. It is a huge challenge to create links in between the real world and its digital counterpart. Difficulties in associating a museum object with the available digital resources could perturb museum visitors that get easily frustrated when it comes to complex in use information and communication systems.
5. Like audio guilds, this didactic approach still treats museum visitors as a passive, homogeneous mass of people, and ignores individuals with their particular interest, expectations, demands, preferred learning styles and social and cultural agendas inside museums.

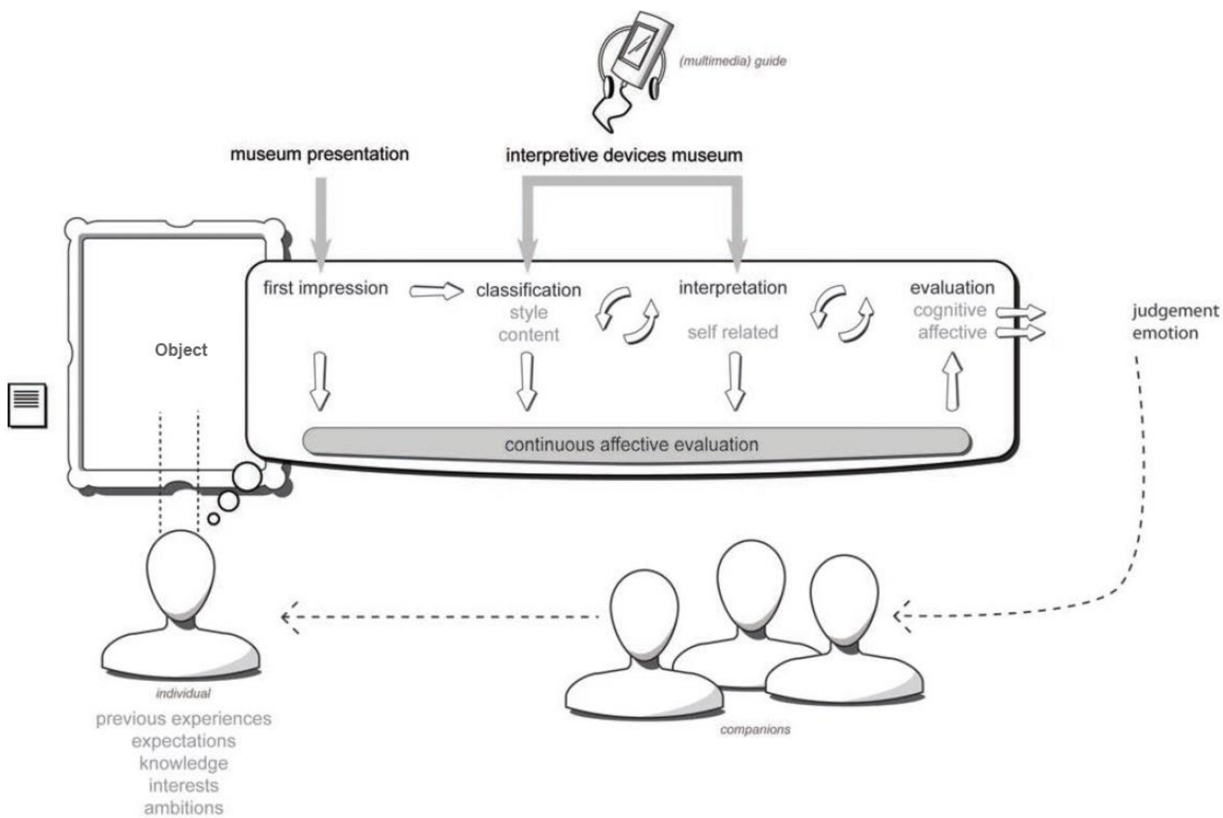


Fig 5.3.1-2: Museum experience using interpretive devices

The model (**Figure 5.3.1-2**) below focusses on the cognitive process that leads to the understanding of an object via all kinds of interpretive devices, which is often a process that often leads to positive and self-rewarding experiences. This process starts when a visitor encounters an exhibit and ends either when a satisfactory emotional state is reached or when the visitor sees no chance of reaching such a state in the near future. The cognitive process can, because of the loops, be indefinitely long; the more time a visitor invests in the classification and interpretation of an exhibit the closer he/she will get to the "real" interpretation.

To conclude, it is clear that audio and multimedia guides are good additions to the group of interpretive devices that museums offer their visitors. Each of the profiled technologies has a significant relevance to museum education and interpretation. However, the criticism that audio and multimedia devices detract visitors from experiencing the object in a museum and decrease social experiences are still valid, which is a characteristic that is shared to a greater or lesser extent by all interpretive devices.

5.3.2 Augmented space

In the context of the museum experience change, the transition from catalogues to digital audio guides can be considered as the first new age revolution which significantly changed the interpretation of the museum environment; and then evolve from audio guides to multimedia guides as the second digital revolution for transforming the culture landscape in an advanced way. Yet, another advent would occur, as an increasing number of cultural institutions around the globe offer a new alternative to their visitors, which is merging augmented reality based features with the exhibit and its surrounding environment, which creates a perfect link in between the physical and digital layer.

As AR technologies are capable of delivering personalised content depending on user preferences, their age and learning abilities with the potential benefit of limitless multimedia delivery through wireless networks. It also helps visitors to focus on the object and enhance their social experiences inside the museum at the same time. As the **Figure 5.3.2-1** shows the adoption of Milgram's reality-virtuality continuum in the museum environment.

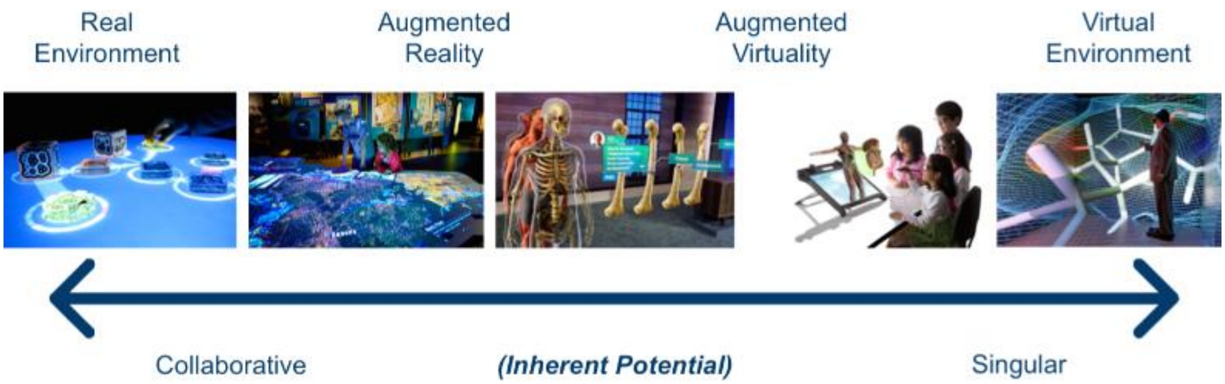


Fig. 5.3.2-1: Milgram's reality-virtuality continuum, and the adoption inside museum environments

Source: Adapted from a taxonomy of real and virtual world display integration by Paul Milgram and Herman Colquhoun. Mixed reality: Merging real and virtual worlds, 1:1–26, 1999. Edited by author

As the author mention in **Chapter 4**, according to the researcher Tiina Roppola, "augmented space is the physical space which is 'data dense', as every point now potentially contains various information, which is being delivered to it from elsewhere. At the same time, video surveillance, monitoring, and various sensors can also extract information from any point in space, recording the movements, gestures and other human activity". (Roppola, 2011) Nowadays, there's various augmentation and monitoring technologies which can add new digital layer to the original physical space, creating an interactive, immersive and multidimensional augmented experience.

For the museum field, exhibitions are always a means of 'translating' expert scientific knowledge into ordinary knowledge for a lay public (Macdonald, 2002). And augmented space is thought to present certain advantages over more traditional ways of providing information (Anastassova, 2007). The co-existence of the physical layer and the digital layer could enhance visitor's understanding by facilitating comprehension of interpretation to be performed (as shown in **Figure 5.3.2-2**). Moreover, augmented reality has been praised for its potential in the comprehension of physical phenomena with more personalised information. Moreover, this environment supports social interaction around the use of collaborative systems, which stresses the importance of focusing on the human use of technology, rather than on the technology itself. More recently, attention to the importance of space and to the use of spatial metaphors for supporting social interaction has also arisen in the technical fields of virtual and augmented reality. (Benford, 2001; Fraser et al., 1999).

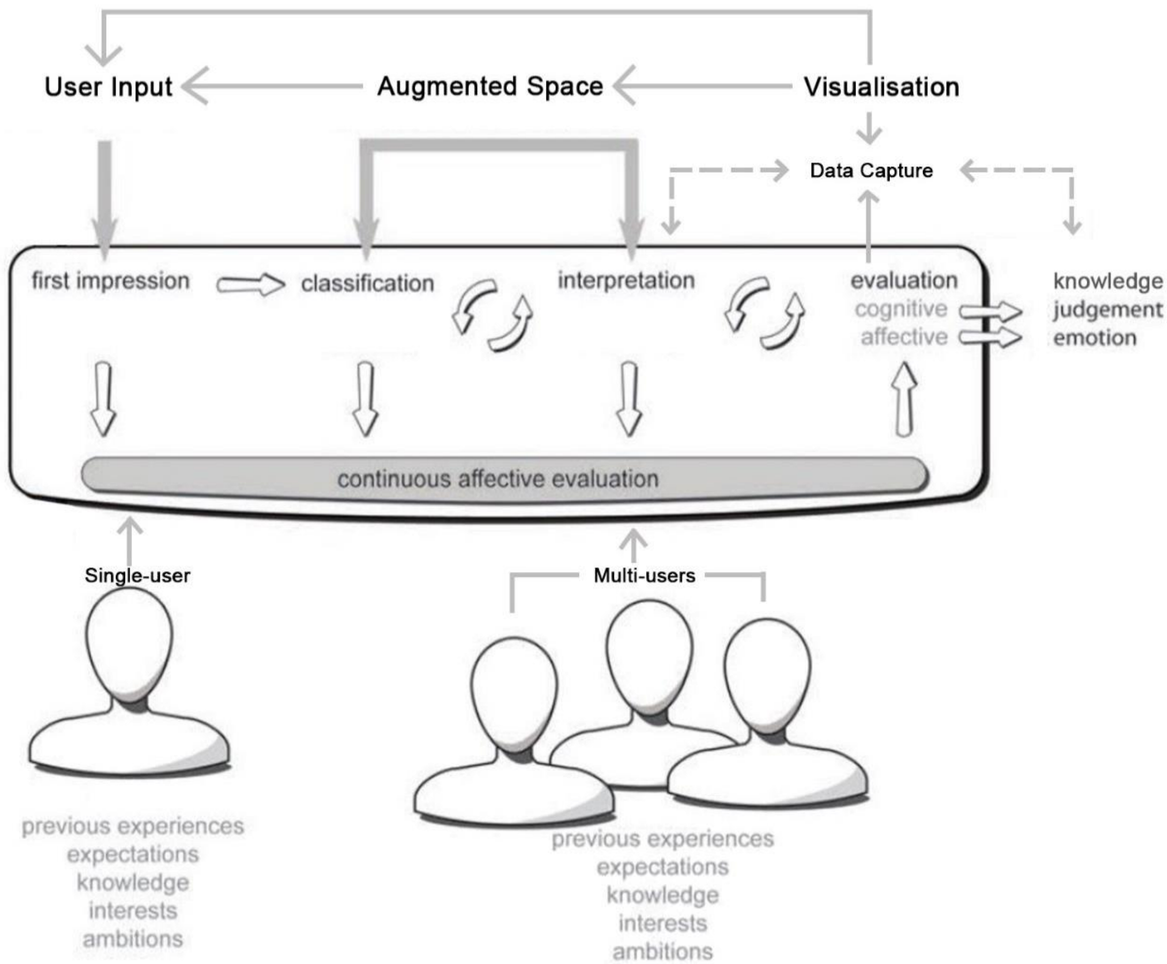


Fig. 5.3.2-2: Museum experience of merging augmented reality based features into the physical space

As mentioned, increasingly Spatial AR technologies involved with larger spatially-aligned optical elements, this new AR technological variation started to be recognised as spatial augmented reality. As Oliver Bimber and Ramesh Raskar claimed, spatial augmented reality provides museum environment brand new digital storytelling and next-generation edutainment tools (e.g., Virtual Showcase and Augmented Paintings). The Spatial Augmented Reality is a new branch of the well-known research field of Augmented Reality (AR) and it is still a fast-growing field. Being a category of the AR field, Spatial Augmented Reality actually adheres to Azuma's definition for Augmented Reality (Azuma, 1997): it combines real and virtual imagery, it is interactive in real-time and registers the virtual imagery to the real world. The substantial difference between spatial and conventional augmented reality lies in the approach that is followed for displaying the virtual imagery in each case.

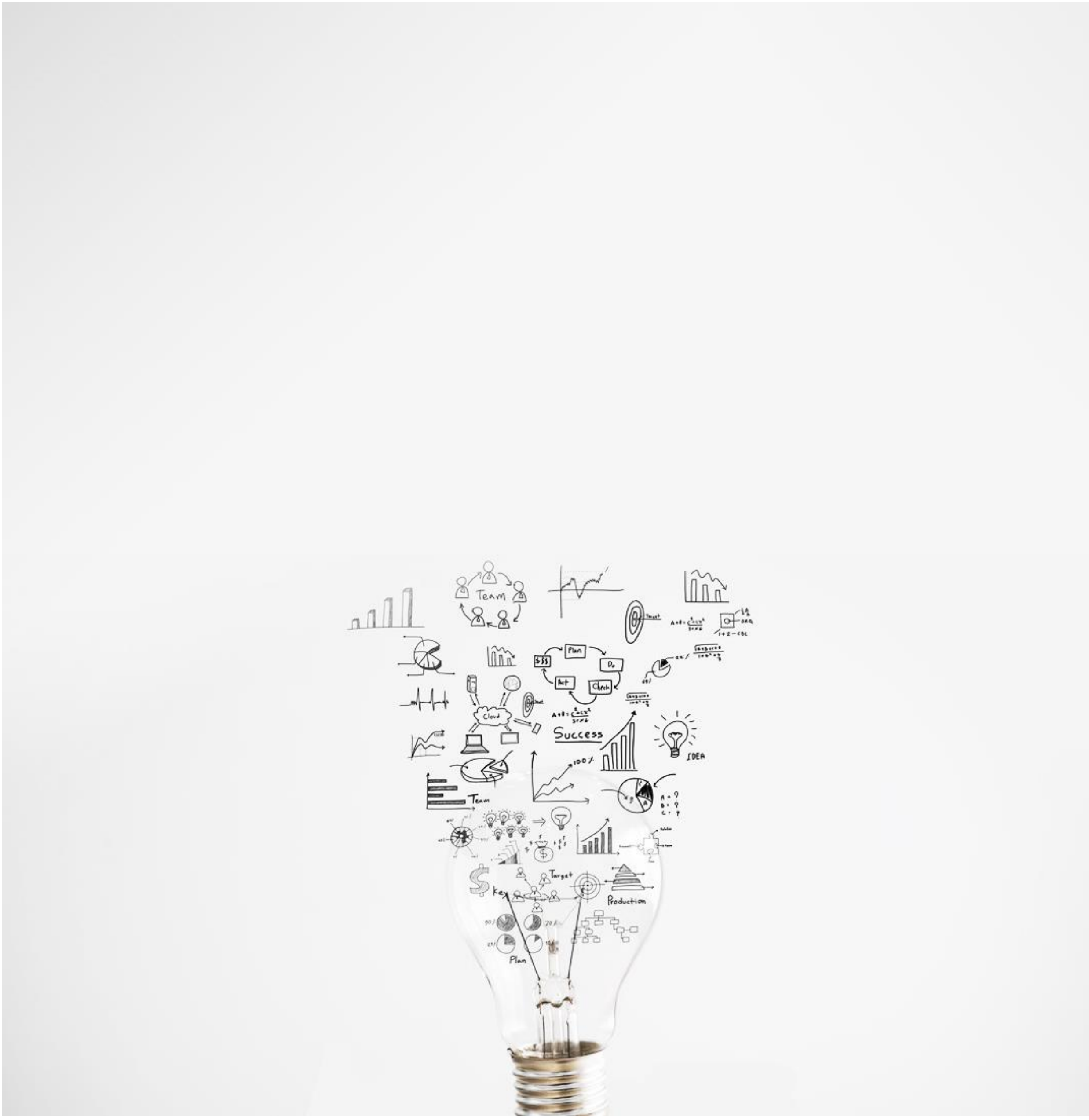
Spatial augmented reality makes use of projection technology and decouples the display surface from the display device. Digital projectors which are the display devices, are used to facilitate the display of computer-generated (virtual) imagery on physical objects or surfaces, which are the display surfaces. The decoupling of display devices and surfaces has the potential to provide a more natural way of interaction, as the virtual information registered to physical objects is directly integrated into user’s environment, i.e. the real world. Besides that, the spatial augmentation does not have to be limited to 2D flat surfaces, as the use of a projector as a display device affords the possibility of illuminating physical objects with complex 3D geometry. The projection onto complex physical surfaces sets the content free from the confines of a limited flat monitor display (Jones et al., 2010). This can revolutionise the way interfaces are designed till now.

According to several researches work like Raskar et al. (1998), Zhou et al. (2008), and Mitasova et al. (2006), there are plenty of benefits offered by spatial augmentation inside the museum environment. First of all, the user does not have to wear cumbersome equipment, like head-mounted displays, therefore Spatial AR is known for its minimal intrusion. Moreover, the eye accommodation is easier, since the virtual content is rendered nearby the real-world location, resulting in motion sickness elimination. Furthermore, the augmentation can be visible to several users, therefore it supports collaborative scenarios. Projection technology provides a large field of view, higher resolution and bright images of virtual objects. A key feature of spatial augmentation is the total merging of the virtual and the physical worlds, which can provide a uniquely immersive experience for museum visitors. From that perspective, tangible experience with interactions that are not possible in a truly physical environment can also be enabled. Finally, the combination of multi-projectors provides a much larger area, undistorted projection, multiple viewing angles, and alleviation of self-occlusion problems. It helps to archive the goal of embedding spatial augmentation systems in museum, which is to make visitors enjoy the combined advantages of natural human interaction and computer-based user interfaces (Raskar, 2001).

5.4 Chapter Conclusion

This chapter explored augmenting space for museum learning. For a visit into the museum to be educative, the learning experience must be intriguing, challenging and stimulating, and it should also be organised and designed to be educative (Hein, 1998). The first part of the chapter focusses on three models of museum learning - the contextual model of learning, free choice learning and constructivist learning. These three aspects define museum learning as a long-lasting change and involve mental representations or associations and hereby a change as a result of experience, which means new learning can be linked up to the previously stored associations. This way what is learned not always correspond with the educator intentions. "As we enter the 21st century, we increasingly view learning as a lifelong process that involves repeated self-directed efforts to improve one's skill in not only academic and professional area of functioning but also personal areas of functioning" (Schunk & Zimmerman, 2008).

The constructivist learning plays an important role in promoting self-exploration and build up the link between users and spaces, which provided a chance for museum visitor to resonate with their experience and gain new knowledge in ways that confirm and enrich their own view of the world" (Doering, 1999). Using augmented space to replace traditional guides in museums means the current museum experience is moving from didactic or instructive to more active or discovery learning, which will enforce the power of the museum education.



Chapter 6.

Interconnecting: Museum Experience and Exhibition Design

Figure: Russell, Vincent. (2017). Illustration. Curated Digital Narrative Project.

Chapter 6. Interconnecting Museum Experience and Exhibition Design

6.1 Chapter Overview

Using the available literature, this chapter focuses on museum experience, and tries to build up the link between previous research and design practice. The first part discusses what is museum visitors' motivations and expectations, and how do they experience and participate in the museum environment. The author also tries to figure out what kind of factors could actually be determining the museum experience. Through the literature research, several authors put forward more or less complete theories about this subject (e.g. Allen, 2003; Csikszentmihalyi and Hermanson, 1999; Heath and vom Lehn, 2008; Hein, 1998; Rennie and Johnston, 2003; Verheyden, 2003), but one of the most recent frequently cited model is still that of Falk (2009), Falk's model explains visitor behaviour, experience and learning in a museum. It as well places visitors' coming to museums in a broader context of their individual and group characteristics. The first part also summarises different identities of 5 visitor groups and close up by pointing out the most relevant aspects of the museum visitor experience model, understanding visitor's identity and the visitor participation in exhibition design.

This second part of the chapter comprises three sections. First, a definition and characteristics of an interactive exhibit are formulated based on a literature review. Basic types of interactives are briefly summarised and the distinction is made between a broad sense interactive and other types. After that, additional categorisations of interactives are presented. All these additional categorisations have a practical meaning (as they relate to purpose, working principle, mechanisms for information transfer), which is most useful for preparing the new interactive exhibition design, planned as part of the following project. Then the author builds the link between 'new interactivity' and museum experience, based on relative researches.

In the last section, the author studies the process of an exhibition design, which provides architects and museum designers a theoretical framework for arranging all the elements in a way that they form meaningful wholes, meets expectations of the museum visitors and eventually construct an 'experienceable' journey inside museum environment.

6.2 Museum Experience Perceived by Visitors

6.2.1 Visitor's motivations and expectations

The question of how people view museums has intrigued researchers and museum practitioners for a long time (Hood, 1981; Hood, 1983; Bigley et al., 1992; Moussouri, 1997; Doering, 1999; Pekarik, Doering & Karns, 1999; Packer and Ballantyne, 2002; McIntyre, 2010). Much research exists that explains the driving forces and mechanisms behind museum visits of people. First and foremost, museums are seen as a leisure experience. People make choices about what to do with their leisure time based on the ability of these activities to fulfil personal needs, desires and lifestyles, Leisure-related needs include for example (Falk, 2009):

- psychological needs: freedom from usual obligations, enjoyment, involvement and challenge;
- educational needs: intellectual challenge and knowledge gains;
- social needs: rewarding relationships with other people;
- relaxation needs: relief from pain and stress;
- physiological needs: fitness, health, weight control and wellbeing, and
- aesthetic needs: response to pleasing design and beauty of environment.

All these needs are represented when asking visitors about their reason to go to a museum (Falk, 2009), as it mention from the last chapter, educational needs (learning) are among those most strongly associated with going to a museum; in this case, it is a combination of leisure and knowledge gains. Museum learning is obviously different than learning in a school setting: it is fun, free-choice, enjoyable, stimulating and transforming. Learning in museums is even described as 'identity work': people go to museums to build or strengthen who they are. So, when choosing how to spend leisure time, individuals prioritise their identity-related needs, and match these needs against the possible leisure options. In this way, a majority of visitors, consciously or semi-consciously, create a set of expectations for the visit long before stepping into the museum. Falk (2009) calls these expectations identity-related visit motivation. The museum experience is, thus, partially influenced by these identity-related visit motivations.

The pre-visit expectation is an idea the visitor develops about what he/she will do in the museum, i.e. his/her plan. During the actual visit, this plan is modified according to what the museum offers the visitor to see and to do. Obviously, not only pre-visit expectations shape the museum experience, but the museum environment itself significantly contributes to the visitors' experience. The museum environment can be best described as a mixture of personal, physical and socio-cultural contexts (Falk and Dierking, 2000; Falk, 2009):

- The personal context is characterised by the knowledge and interests that the visitor has. This knowledge and interests guide the visitor through the museum visit. If he sees exhibits related to his knowledge or interests, he will stop and study the relevant objects in great detail.
- The physical context is expressed by well-designed exhibitions and programs; the careful use of colour, texture, and lighting combined with skilfully written scripts and labels are extremely successful at getting and focusing visitors' attention.
- The socio-cultural context relates to the visitor's social and cultural background, and to whether it's a group or individual visit. When visiting in a group, conversation with others and asking questions enhance the understanding of the exhibits presented in the museum. The socio-cultural background influences which rooms visitors want to see, and how they perceive exhibitions.

Finally, the visitor makes meaning of what he/she saw and did in the museum by, consciously or semi-consciously, looking back at the visit (Falk, 2009). Meaning making takes place through determining satisfaction and producing memories. Two aspects play a role in this process, i.e. choice and control the visitor had in a museum, and emotions he/she experienced during the visit. A high level of choice and control gives the visitor the opportunity to do and see the things that suit his identity, knowledge and interests; this enhances the level of satisfaction about the visit. Emotionally rich and positive moments during the museum visit, encourage the creation of memories, as such moments are striking and therefore perceived as important (Falk, 2009).

The visitor now defines whether he is satisfied with the museum experience. He/she makes the assessment by balancing the pre-visit expectations with what he actually experienced in the museum. When doing this, perceptions of the visit are more important that the actual experience. In the next step, memories of the visit are created. Often, only certain aspects of the museum visit tend to 'stick' in the visitors memories. The memories that stick are usually selected through a personal identity 'lens' every visitor uses. This personal lens is shaped by the identity-related visit motivations that are developed before visiting the museum. After a while, these memories are combined into a larger picture, describing going to museums in general (Falk, 2009).

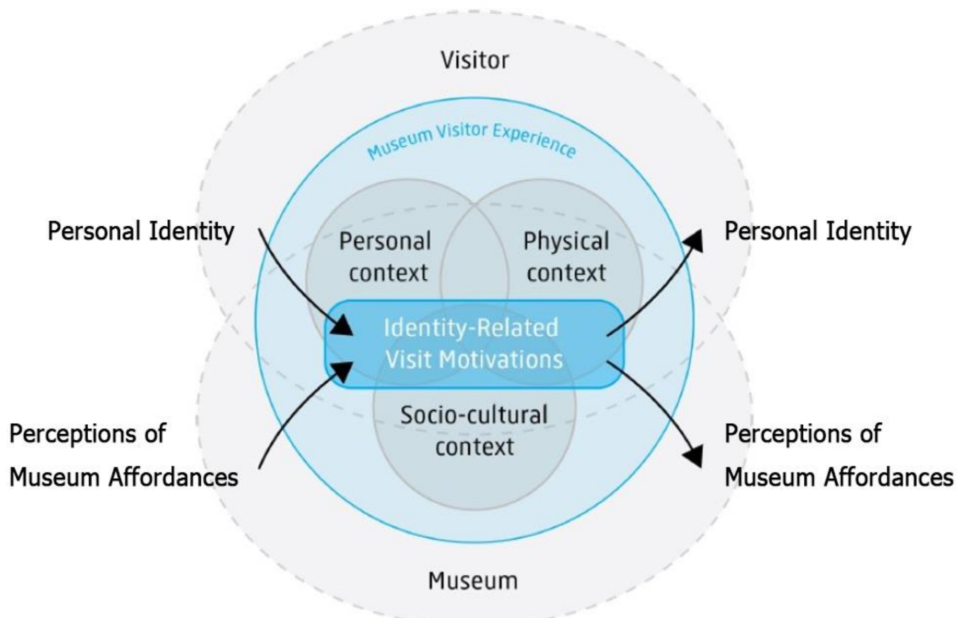


Fig. 6.2.1-1.: The Museum Visitor Experience Model

Source: Falk, 2009

Figure 6.2.1-1 summarises the museum visitor experience model. The museum visitor experience model points out that the visitor experience is assembled in several steps. Before the visit, visitor identity and perceptions of museum affordances form foundation for the decision whether to go to a museum. At this stage, thus, the visitor's reasons for a visit are related to his personal identity and what he thinks the museum can offer him in terms of leisure (identity-related visit motivations). While being in the museum, the identity-related visit motivations are the driving force behind what the visitor sees and does, which in turn determines his museum experience. The museum experience is also shaped by the context, i.e. the visitor's personal context, the physical context of the museum and the socio-cultural context, in which it happens. Finally, the visitor makes meaning of the museum experience by creating memories about the visit, and deciding whether the visit was satisfactory. These aspects finally influence the visitor's perception of his personal identity and enhance the visitor's understanding of museum environments (Falk and Dierking, 2000; Falk, 2009). Noteworthy, Falk's model obviously applies to the grown up people; it has little to do with children. Children on the other hand do not necessarily make their own decisions about visiting a museum. In most cases, these are their parents (or grandparents) that make these decisions for them. The decisions are based on parents' assessment of children's needs which takes us back to the Falk's model of the museum visitor experience.

6.2.2 Visitor's identity and participation

In the museum visitor experience model, the visitor's identity is essential. Falk (2009) introduces five most common roles that visitors take on in the museum. These roles explain the behaviour and the experience of a museum visitor. According to Falk, conclusions for museum design and museum marketing can be drawn from studying these roles. The five roles include: explorer, facilitator, experience seeker, professional/hobbyist and recharger; they are described below. A summary table is attached below; it compares the roles with each other.

Museum explorer - The explorers has the need to satisfy personal curiosity and interest in an intellectually challenging environment. They like to brows in a museum, looking for particularly attractive or outstanding objects; and they love 'intellectual bargains'. When browsing, the explorer often doesn't follow the standard museum route. Visitors' pathways are not linear and may seem illogical. The explorer likes to have a high level of choice and control; he doesn't like to be prescribed where to go and what to do. The exhibitions that the explorer likes support exploration: they are rich in detail and offer him opportunities to train his mind.

Explorer are curious and want to engage in a process of discovery. Information offered to the explorer should be visually and intellectually clear so that he can quickly determine if he/she wants to engage in this discovery. Museum explorers visit museums relatively frequently, so they understand how museums "work". In a new museum, they expect their visit be supported by clear maps, signage, object labelling, and knowledgeable and responsible staff. They are very likely to read brochures, labels and to use guides. Next to this, they as well often use remaining facilities of the museum, such as museum shops, restrooms and cafés. The explorer is the least socially oriented visitor; he/she doesn't have the need to visit in groups. He/she does like to interact with staff; to ask questions about the exhibitions to feed his curiosity. At the completion of his/her visit, the explorer often makes inquiries about future exhibitions to support his next visit.

Experience seeker - The experience seeker has the aspiration to be exposed to things and ideas that exemplify what is best and intellectually most valuable within a culture or community. He is not a visitor that goes to museums regularly. The experience seeker doesn't want to learn about everything what's in a museum, but about the most important object or exhibition; he comes to see the highlights of the museum. The museum should support him in doing this. Maps and pre-visit information is most useful, especially a 'guide to the museum's best' comes in handy. The experience seeker doesn't stop to ask for directions, often because he is on a tight time schedule. Therefore, the museum staff should be trained in noticing when the experience seeker needs help, and provide him with it. Information about general exhibitions should be easy to grasp for the experience seeker. The icons or highlights of the museums should provide in-depth information, so that he can understand the exhibition in detail and offer information to answer the questions that the one-time experience seeker might have. Next to this, the experience seeker wants his whole experience to be memorable: a clean and attractive museum, friendly staff, the washroom, gift shop and the café are all important. All of these aspects are perceived as a single whole.

Professional/hobbyist - The professional/hobbyist has the desire to further specific intellectual needs in a setting with a particular subject matter focus. Clearly, his prior knowledge and interests are highly relevant, as is the interaction with professional staff and the museum orientation. He is a regular visitor of museums. To make the visit satisfactory for the professional/hobbyist visitor, the information provided by the museum should be easily accessible and the guidance professional. Professionals/hobbyists know exactly what they want, therefore they rarely follow the pathway as prescribed by the museum; instead they go straight to the object of their interest. Noteworthy, the traditional well-designed exhibits don't work for this group. Professionals/hobbyists want direct access to the object they're interested in: they won't read labels or look at the whole exhibition around the object. Professionals/hobbyists are interested in getting behind the scenes to gain more information: they will follow workshops, tutorials and any of the museums activities that offer them opportunity to deepen their knowledge or interest. Professionals/hobbyists see themselves as experts in a certain area.

Recharger - The recharger has the yearning to physically, emotionally and intellectually recharge in a beautiful and refreshing environment. All the recharger wants is a nice place in which he can relax. They are highly sensitive for the aesthetics of the place and to crowding (which they don't like). Often, rechargers are interested in and like the museum's exhibitions, but this is not primarily why they come. Rechargers are often repeat visitors so they know what a museum can offer them, and they know their way around museums. When visiting a new museum though, good maps, signage, information and knowable staff are highly appreciated.

Facilitator - The facilitator has the wish to engage in a meaningful social experience with someone whom he cares about in an educationally supportive environment. They have a strong desire to support what's best for their loved ones or companions. There are two different facilitators: facilitating parents and facilitating socialisers. The facilitating parents want to occupy, engage and stimulate their children. The prior knowledge of the children, rather than their own, is significant. The facilitating parent uses the knowledge of their children to guide the visit and to support the children's learning and enjoyment. When starting the visit, facilitating parents usually move quickly into the museum, following their enthusiastic children. Therefore, the museum map, its signage and guidance have to be clear, such that the parents can absorb and process this information quickly and efficiently. When visiting a museum designed for a general audience and not necessarily for children, the signs directing the visitors to those parts of the museum which are suitable for children are much appreciated. Facilitating parents work hard to help their children understand the museum, so they often intensively use object labels to explain to the children what is on display. If information about the exhibition is displayed in several places, the parents will find and use this information more easily. The clearness of exhibition and information should be well designed. Friendly floor staff is important for the facilitating parents, mainly to help finding the restroom, café or a certain exhibition. Facilitating socialisers use the museum as a stage for their social agenda. Meeting the needs of this group is easy; all the museum has to do is keeping the 'stage' clean, friendly and accommodating. The facilitating socialiser gladly welcomes quiet spaces which support their socialising needs.

Type of Visitors / **Guidelines**	**Explorer**	**Experience Seeker**	**Professional / hobbyist**
Museum going frequency	Regularly	Infrequent	Regularly
Amount of whole museum vising public	Largest	Small	Smallest
Museum membership	Sometimes	No	Sometimes
Interest	Museums related to knowledge and interest	Must see museums	One specific field of interest
Key description	Curious, enjoys learning	Tourists, like fun and culture / learning	Critical, influential
Museum related needs	Satisfy personal interests and curiosities, expand horizon	Collect an experience, see the destination, building, what's iconic or important on display	Achieve one narrow, personally-important task
Participation in museum	High: see whole museum in outline, participate in lectures and programs	Low: only motivated to see the museum in general, and mostly in one aspect of the museum. Does want a whole museum experience	High: interest in one specific topic and how museum conveys information about that, participates in subject related workshops and seminars
Museum routing	Browsing, a-linear	Straight to the museum's best	Straight to the subject of interest, avoid crowed (temporary) exhibitions

Role of socialising	Not important: exploring is main activity. Professional staff is appreciated for content related information	Important: having nice day with relation, make memories together	Family / friend visits not important, do appreciate professional staff
Museum design	Exhibition programs, interpretive tools that make it easy to explore, exhibition that are rich in detail and information, layered labels and flexible guides, good maps and signage.	Pre-visit information about what to do, clear maps, signage and ordination system in the museum, guide to the best of the museum, interpretive aids to understand the main idea of the museum but the icons should be rich in detail and information	Maps, signage and orientation are important for professional visitors, should make space available for groups working in topic related. Good description adjacent to the object.

Type of Visitors / **Guidelines**	**Recharger**	**Facilitator**	
		Facilitating parents	Facilitating socialiser
Museum going frequency	Regularly	Regularly	Regularly
Amount of whole museum vising public	Average	Average	Average
Museum membership	Sometimes	Sometimes	Yes
Interest	Tranquil, beautiful places in museums	All museums for children	Specific museum nearby
Key description	Strong sense for aesthetic, epicurean	Altruistic, knowledgeable (grand)parents	Altruistic, great social companion
Museum related needs	Reflect, rejuvenate, back in the wonder of the place	Accommodate the needs of (grand)children	Accommodate the needs of important relation and spend time in an attractive space
Participation in museum	Average: use the museum as setting to relax	Low for parents, high for children; children see whole museum and enrol in extra activities like workshops and science classes	Low: museum servers as platform for social activities

Museum routing	Sitting in a quiet place, observing	Walking / running through museum, occasionally explaining things to their kids	Walking through museum and chatting, occasionally looking at exhibition
Role of socialising	Not important: it's more like a self-explore journey for them	Important	Very important
Museum design	Everything should be taken very well care of	Family guides / backpackers, clear and quick to internalise maps, signage and orientation, child-friendly exhibits signage, clear and well-placed information, exhibitions that support intergenerational interaction	Well-designed; educationally supportive museum environment, facilitates meaningful social experience and deep engagement

Table 6.2.2-2: The concluded features of different types of visitors and guidelines for museum.

Source: Based on Falk J. H., 2009. Edited by researcher

After reviewing the visitor's identity inside the museum environment, the visitor participation is another relatively new discipline in museum research, comparing with museum experience study. Stuedahl and Smørdal (2011) point out that there are several ways for visitors to participate in the museums activities; through contribution, collaboration, and co-creation. A different definition of participation is used by Taxén (2004) and Tzibazi (2013), where they are applying in their studies participation happening while designing or redesigning the technology together with the end user as an equal collaborator. The definition is grounded in principles from participatory action research, where the end user is invited to join the design process as a co-designer together with the educators from the museum (Taxén, 2004) or with the artists (Tzibazi, 2013). In the museums, knowledge about visitor's experiences has traditionally been gathered by applying museum visitor studies (Bandelli, 2014). These focus on the demographic data gathered during assessment of an exhibition. The development and design of the exhibition and museum outreach programs itself, has traditionally been based on the knowledge and assumptions of the museum staff, like curators or subject specialists; in some cases, including educators, designers, artists or technicians. The end-users were taken to account in the testing activities when the installation was complete or in a beta phase, where testers were selected by the museum staff. Taxén (2004) explains that with time employees like educators and evaluators where included in the development process, so that they could contribute to the "visitor knowledge" in earlier design phases. However, the end users of the installations are rarely invited to participate as a design partners, as a lot museums haven´t acknowledge fully the meaning of this type of participation.

6.3 Interactive Experience in Museums

After reviewing the museum experience perceived by visitors, the author moves the attention to the fundamental component of the interactive exhibition – interactive exhibits. The second part of the chapter first comprises a definition and characteristics of an interactive exhibit are formulated based on a literature review. Basic types of interactives are briefly summarised and defined. Then the subsection provides an additional categorisation of interactives exhibits. All these categorisations have a practical meaning in the exhibition design industry, which is useful for preparing the design-based project in **Chapter 8**, which planned as part of this PhD research.

6.3.1 Definition, characteristics of interactive exhibits

This section describes the definition, characteristics and types of interactive exhibits. The goal of the section is to clarify what an interactive exhibit is. Museum professionals do not always agree as to what comprises an interactive exhibit (e.g. Adams et al., 2004; Bitgood, 1991; Caulton, 1998; Hein, 1998; McLean, 1993; Pekarik et al., 2002). Some of them believe an interactive exhibit is an object with educational goals (Caulton, 1998). Others think that an interactive involves touching or manipulating something (Bitgood, 1991; McLean, 1993; Caulton, 1998; Hein, 1998; Pekarik et al., 2002). The involvement of the user, and that he is engaged on sensory, emotional and intellectual level is another viewpoint on interactive exhibits (Pekarik et al., 2002; Adams et al., 2004).

The definition of an interactive exhibit that will be used in this study incorporates these different viewpoints (Caulton, 1998; Adams et al., 2004): An interactive museum exhibit is an object which an individual or groups of individuals can influence (in shape or in content), by involving themselves at the sensory, intellectual and/or emotional level, in order to understand real phenomena and/or learn about museum items. In this definition, the user can influence the interactive object. There is reciprocity of action between the visitor and the interactive; that is, the device reacts to the visitor's action and the visitor in turn to the response of the device (Rafaeli; 1988; Bitgood, 1991; Kiousis, 2002). In other words, there is a cause-effect relationship between them and the object: feedback plays a critical role in interactivity. McLean notes: "Interactive exhibits are those in which visitors can conduct activities, gather evidence, select options, form conclusions, test skills, provide input, and actually alter a situation based on input" (McLean, 1993).

The fact that the user can alter a situation is essential, the involvement of the user is even more so. The user should be involved at the sensory, emotional and intellectual level (Adams et al, 2004 and Hamstra, 2005). Most of the times the interactive object primarily focuses on only one of the three levels (sensory, emotional or intellectual), but the other levels have to be addressed too. It is important that the user is active on all levels because he has to feel engaged in the interaction. The interactive exhibit should not only offer possibilities to be altered (to be hands-on), but it should engage the user intellectually (minds-on) and emotionally (hearts-on).

All in all, the user not only does something, but as well thinks about what is happening in the interaction and this influences his feelings. In the nature of interactive exhibits, social interaction plays an increasingly significant role. The learning process in museum settings in much more efficient and memorable if conducted in groups, through exchanging observations, remarks, encouraging each other for action, questions, answers, discussion etc. with those who came together to the museum (Adams et al., 2004; Falk et al., 2004). A good interactive should make it possible for the social interaction to occur.

The following model (Kiousis, 2002) is used to describe the principal characteristics of modern interactives, as **Table 6.3.1-1** shows the characteristics of an interactive exhibit. The model of Kiousis characterises interactivity using three dimensions: interaction process, physical characteristics of the object and behaviour of the visitor (Kiousis, 2002). For a high interactivity level, the interactivity process should be reciprocal: the messages of sender and receiver should be related and there should be a high level of feedback. The physical characteristics of the object should stimulate multiple senses and offer several options to explore. In other words, the interactive needs to enable the visitor to take different actions. For interactivity in the museum it is also important that the subject and content of the interactive exhibit are relevant to the visitor. The visitor should be actively engaged in the interaction, and the engagement should take place on multiple levels.

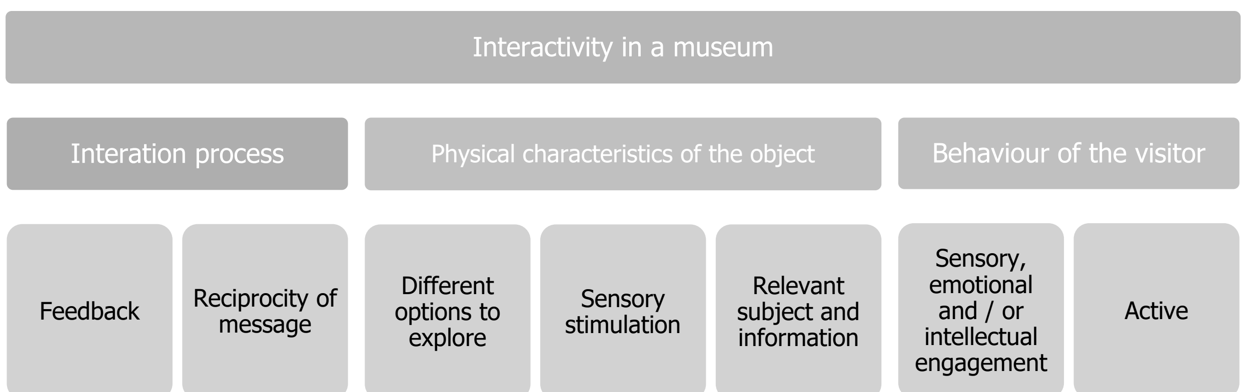


Table 6.3.1-1: Characteristics of modern interactives in museums

Source: Adapted from Kiousis, 2002

6.3.2 Categorisations of interactive exhibits

Interactive exhibits can as well be categorised in other ways, for example: by purpose of the interactive, working principle and type of information transfer. This section explains each of these aspects. **Figure 6.3.2-1** shows the three different ways in which interactive exhibits can be categorised.

In summary, the term "interactive" is sometimes used interchangeably with "hands-on" devices (allows touch but not necessarily interaction), or "participatory" exhibits (emphasis on visitors action rather than the exhibit's ability to react). Some authors claim this is not fully correct (Bitgood, 1991; McLean, 1993; Pekarik et al., 2002). Simple "hands-on" and "participatory" exhibits do not provide as much (if any) feedback. These exhibits can be, however, altered and most importantly they often engage the user's mind and heart in the interaction. The different types of interactive exhibits, including their concrete examples, are available for instance, from the work of Bitgood (1991) are attached in the following subsection (Mc Lean, 1993; Pekarik et al., 2002).

Type of Response Engagement	**Examples of Exhibition Type**	**Possible and/or Intended Impact**
Simple Hand-on (Exhibit prompts the visitor to touch, climb, etc.)	1. Touching aerolite, animal skeleton and fur. 2. Climbing on climber's playgrounds, or a statue of an animal. 3. Dressing up in scientist's or firemen's clothing and do cosplay inside museums	1. Produces sensory and/or perceptual learning. 2. Focus visitors' attention on surrounding environment or an object. 3. Promote affective learning. Create an increase in instinct motivation and interest, change in attitudes, etc.
Participatory (Exhibit prompts a response and the outcome is used to teach a point by comparing it with some other response or standard: goes beyond simple hands-on)	1. Comparing physical fitness (or some other visitor responses) with each other / animals. 2. Feeling several objects and comparing them on their characteristics such as roughness, coolness and elasticity etc. 3. Assembling an animal's skeleton and comparing with a correct assembly.	1. Teach similarities and differences between objects or events. 2. Increase attention to objects the object, and promote self-reflection and engagement for group visitors. 3. Produce an increase in interest and motivating behaviour (affective learning).
Interactive (Exhibit prompts a response which changes the state of the exhibit; the change is under the control of the visitor.)	1. A label with a flip panel. 2. Devices with controls (cranks, buttons, levers etc.) in which a response on the control makes a change in the exhibit (Lighting, sound, objects' position, etc.).	1. Teach of cause-effect relationships (using either discovery learning or guided learning). 2. Teach similarities and differences between objects, events.

level 1: Simple engagement (e.g., press a button, light turns on) Level 2: Prolonged engagement (e.g., interactive computer game)	3. Interactive computer tutorials, self-testing games, devices, etc. 4. Magnifiers (magnifying glass, microscope) that when used correctly reveal what was previously unseen.	4. Focus visitor's attention on object. 5. Affective learning (increase in interest, attitude change, etc. 6. Self-testing of visitors. 7. Conceptual orientation of visitors.

Table 6.3.2-1. Types, Examples, and Impact of Interactives

Source: Based on Bitgood, S. 1991: Suggested Guidelines for Designing Interactive Exhibits. Visitor Behaviour. Edited by researcher

The purpose of an interactive relates to various kinds of experiences the interactive exhibit should engage the visitor in. Most common purposes of interactive exhibits are: sensory, intellectual or emotional stimulation (Csikszentmihalyi and Hermanson, 1999; Adams et al., 2004). When stimulating senses, the vision, hearing, touch, scent or taste is activated to engage the visitor in an experience. Intellectual stimulation focuses on making the visitor process some information. The most common stimulation of the intellect is by transferring knowledge. Finally, the stimulation of emotion is used to make the visitor feel something. For that reason, the working principle of an interactive exhibit should consider the design factors of the object embraced in the physical shape. More specifically, the working principle of the interactive needs to figure out what makes the interactive work. Broadly speaking, interactives can also be divided into: spatial, computer (screen), mechanical/electric and user (power) driven interactive exhibits (Bitgood, 1991; Gammon, 1999).

The contexts of the museum visit, the personal, physical and socio-cultural contexts, are still highly relevant because an interactive exhibit is part of these contexts. The characteristics of an interactive exhibit should fit the personal, physical and socio-cultural contexts of the museum visit. We need to realise that an interactive exhibit should contain information that suits the visitors' prior knowledge and interests. Next, the interactive exhibit should be successful at getting and focusing the visitors' attention. Also, the interactive exhibit should fit in the setting of the whole exhibition. And finally, the interactive exhibit should support social interaction of the visitor, as the connection between the museum contexts and an interactive has impact on a satisfactory museum experience.

6.3.3 'New interactivity' and museum experience

Concerning this 'new interactivity' in museums, Witcomb alludes to "the emergence of the new museology, a field of study which critiques museum practices in relation to their social, economic and political contexts" (Witcomb, 2003), to illustrate how the museums' absolute claims and authority are being challenged. At the same time, the ubiquity of AR technologies and the growing impact of digital age, claims that the trend of technology integration "has brought widespread changes to contemporary museum practices", particularly to the status of objects within museums in terms of their authority to speak or mean (Witcomb, 2003). The impact can be seen on a practical level where current exhibitions consist of non-collected objects such as multimedia applications and other design elements, and also on a discursive level where these new media make the museums' content available beyond their walls, making museums readily accessible and popular.

According to the literature studies, there are two mam implications with the changes towards new media and technologies in museum exhibitions. First, it has to do with the potential for more social interaction and the issue of accessibility. The author refers to Marshall McLuhan's idea to explain the potential for more social interaction, which considers the non-hierarchical communication style of electronic technologies to be conducive to socio-cultural interaction. Witcomb then discusses George MacDonald's (1987) argument about the issue of accessibility, George MacDonald advocates the use of technologies in the form of experiential exhibitions where the objects are not separated from the viewers (as cited in Witcomb, 2003). This is to help museums remain relevant in the modern information society. With less focus on the objects in exhibitions, museums no longer need to make absolute claims. Exhibitions thus can be more open to interpretations with the aid of exhibition techniques such as graphic images and audio-visuals. Second, the changes towards technology integration induce the rise of constructed new narrative for the augmented space in museums.

Researchers turn to examine interactivity in museums as a result of technology integration in exhibitions, and finds that it is not necessarily the technologies used that drive the interactivity in museums, but rather the narrative structure. Traditionally, exhibitions have been designed to communicate a single, linear narrative, which is then supported by spatial arrangements and artefact displays expressed in a one-way flow of the exhibition space. However, Witcomb asserts that the interactivity via technology integration does not guarantee a change in the one-way communication, but a re-conceptualisation of exhibition spaces does. The conditions essential to such an intention include acknowledging the fragmentary nature of history (Ernst, 2000, Geertz, 1973) and accepting multiple interpretive voices (Hooper-Greenhill, 2006) The problem that comes with this approach is that in the pursuit of democracy museums potentially exclude the general public, as this type of exhibition often requires more background knowledge on the part of the audiences to form their own interpretation and can therefore become less accessible.

Witcomb considers narrative as a design issue, she presents an idea similar to the one given by Hooper-Greenhill (2004). She also emphasises the need to see communication as a two-way process, which is without a predetermined discourse in order to allow the visitors themselves to process information and produce their own meanings. This consideration thus leads to designing smaller theme/display units within an exhibition that stand on their own and arranging them in a meandering manner, which is less controlling than the linear style. Witcomb notes, "The difficulty for those museums who wish to be less didactic and more interactive is to achieve a balance between multiple points of view while maintaining an editorial line which is not reductive" (Witcomb, 2003).

The quality of, and potential for, technology integration and museum experience lies in its interactivity. To many (Jones-Garmil, 1997; Fahy, 1999; Witcomb, 2003; Hooper-Greenhill, 2004; Alexander & Alexander, 2008) the trend promises more social interactions both within and beyond the museums' walls. However, not all authors agree on the benefits of such a trend. For instance, Henning (2007) argues that such interactive technologies and interactive exhibit actually elicit passivity from the audiences. These different views often relate back to the more profound issue of the museums' purpose in society/ culture and more specifically, of their transformation. While the debate on the role of museums, either as temples or forums is beyond the purposes of this thesis research, the author of this thesis does not take a strong position on either side of the debate. The main intention is to explore and propose a good reference for interconnecting the early curatorial interpretation and the final experiential representation for science museum exhibition practice.

6.4 Design Processes between Theory and Practice

The last part of this chapter focus on the exhibition design process, and tries to examine the 'backbone' of exhibition design aspects which should be performed adequately in exhibition design process in the real practice. Firstly, it is necessary to understand the fundamental design theories to get a clear framework for practical exhibition design. Jones in 1984 has concluded that the design process is need to resolve the conflict that exist between creative thought and logical analysis, as it is illustrated in **Figure 6.4-1**, which is dealing with design management involved in new product strategies (Langrish, 1994). In the same year, Sethia claimed that the design process is as important as project management, and it is critical to the quality of the final product (Sethia, 1994). Cleland and King state that designers define their design process based upon a range of precedents, adapting or varying them to suit the design requirement (Cleland and King, 1993; cited in Newton, 1995).

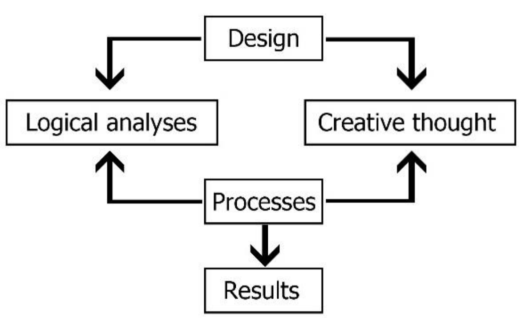


Fig. 6.4-1: Jones's abstract meaning of design process

Source: Adapted from *a Method of Systematic Design* by Jones, 1984.

A descriptive model is widely recognised to fall into three phases: analysis, synthesis and evaluation, as the **Figure 6.4-2**, and is employed in numerous descriptions of the design process model (Jones, 1984;

Newton, 1995; Roozenburg & Eekel, 1995 and Lawson, 1997). Such design process model is employed by designers to develop a solution to a certain design problem. This process is representing a feed-back cycle to formulate design problems and develop design proposals with certain aims.

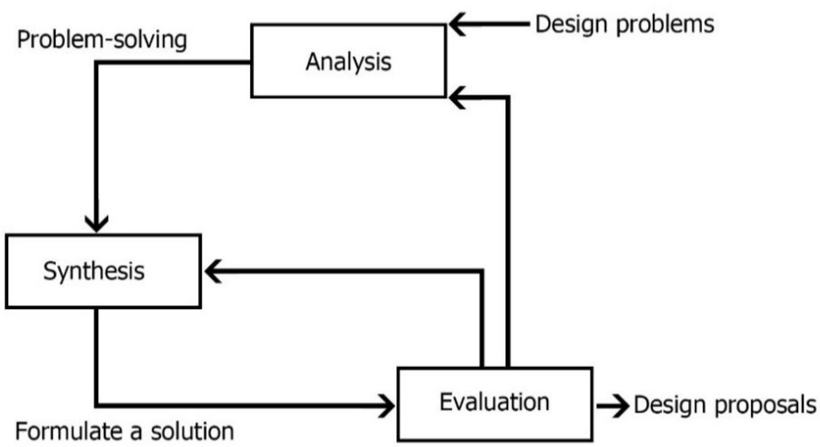


Fig. 6.4-2: The diagram shows that the design process involves interrelated analysis, synthesis and evaluation activities representing a feed-back cycle to formulate design problems and develop design proposals

Source: Adapted from Roozenburg & Eekel, 1995, edited by author.

In the year of 1994, Portillo further concludes the study of criteria for the design solution addresses the integration of processes and structure. Such criteria contribute to the imaging and shaping of the design framework (as the **Figure 6.4-3** below).

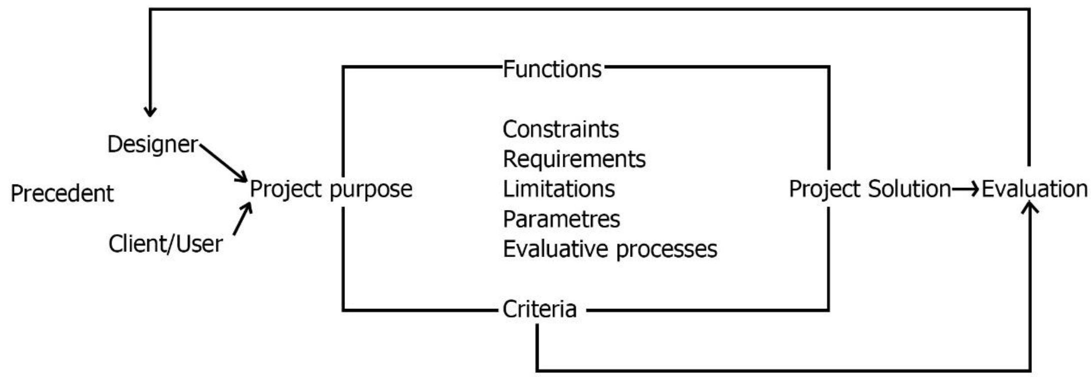


Fig. 6.4-3: Portillio's design process structure

Source: Adapted from *Bridging Process and Structure through Criteria* by Portillo, 1994; edited by author.

Based on those descriptive models above, there's also two prescriptive models which both use comprehensive checklists to help users to understand the design process in UK. The first one is the British Standards 7000 design process, which was published in the year of 1984 (BS 7000, 2008). BS7000 is prescriptive and detailed, which means it can be applied to management and service at the early stage (Hollins, 1994), as the **Figure 6.4-4** below.

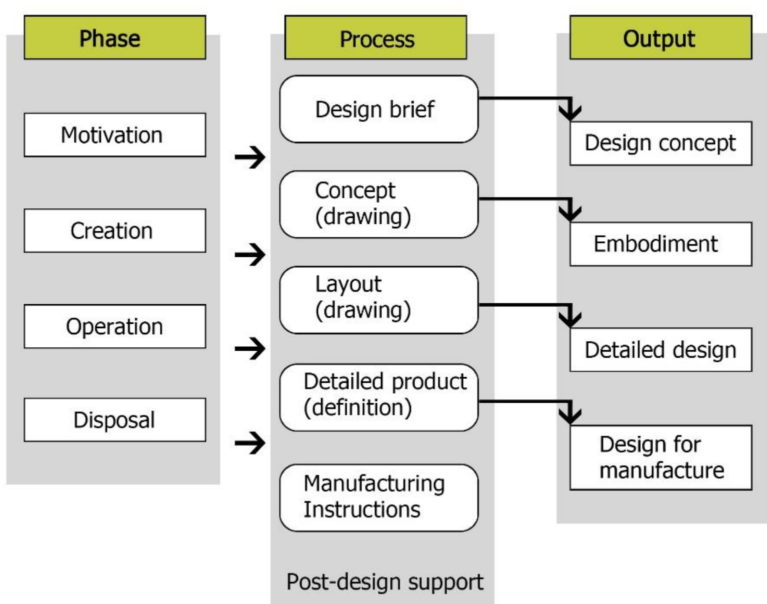


Fig. 6.4-4: The guide of managing the design process of manufactured products from British Standard 7000.

Source: Adapted from BS 7000, edited by author

Phase	**Process**	**Output**
Concept Phase	Control. Design Inception. Analysis of opportunities. Analysis of business concepts. Formulation of the project. Preliminary evaluation.	Perceived opportunities. Alternative business & product concepts. Identification & selection of preferred business concept & product characteristics. Preliminary definition & product proposal. Permission to proceed.
Feasibility phase	Feasibility study. Refine characteristics. Develop project configuration. Evaluation and sanctioning of the project.	Criteria of acceptability to organisation. Product design brief. Project plan & resource plan. Project approval.
Design/ Development stage	Design concept development. Outline design.	Preferred option. Product resolution.
Implementation	Assemble design team. Concept design. General arrangement design. Detailed design. Provision for manufacture and delivery. Introduction and product launch. Sailing and use, Feedback.	Specification for product. Confirmation of performance.
Manufacturing	Design support for manufacture. Product launch. Monitoring 'in-use' performance for feedback. Evaluation of the whole project.	Product package. Fulfilment of business objectives. Customer requirements. Potential Improvement. Product enhancement. Identified design process Improvements.
Termination phase	Decommissioning disposal	Handover of responsibilities. Implementation.

Fig. 6.4-5: Idealised process for exhibition design, adapted from British Standard 7000.

Source: Adapted from BS 7000, edited by author

British Standards 7000 provides general principles and techniques for the management of design process. The purpose of giving responsibility for design is to ensure that BS 7000 users have an understanding and a clear sense of direction with respect to design (BS 7000, 2008). This process model is a linear sequence of working phases which represents design and individual design tasks in detail (**Figure 6.4-5**). As Newton mentioned BS 7000 process model attempts to provide broad criteria and information within which design can be managed, they should be considered as checklist, describing what should be done at what stage of the design procedure (Newton, 1995). However, the author also noticed that the model is not detailed enough to schedule specific activities nor define each task during the design procedure.

The importance of adopting and planning with innovative technologies are also emphasised inside the latest BS 7000 – 1:2008 / Design management systems, as the document mentions, it is essential to "anticipate technological advances and plan how they might be harnessed" (BS 7000, 2008). It believes that the development of the final products could depend upon new technologies becoming available, and the designers should study that how targeted markets are likely to respond to those innovative applications. It suggests two ways of organisations can proceed in real practices: 1) Identify design products that could be developed along the innovation highway[9], then strive to develop the required technologies. 2) Identify technologies used or in development elsewhere, then check how these might be applied. Maps of future technology incorporated into the innovation highway could reveal gaps in techniques, materials and processes, which might be filled by improved products and new offerings when the relevant information becomes available.

RIBA Outline Plan of Work is also a prescriptive model for design process, which was first published in the year of 1967. The model shows a series of work stage that British architects have to follow in order to complete their design work (Tankard & Ray, 2005; Lin, 2014). *RIBA Outline Plan of Work* provides British registered architects and relative designer a guideline or a basic framework for architectural design process

[9] Innovation highway here is the permissible route over which long-term future products and services will be planned.

as an official document for a logical sequence of procedures. Similar with BS 7000, these two prescriptive models have been widely adopted in the UK (Tankard & Ray, 2005).

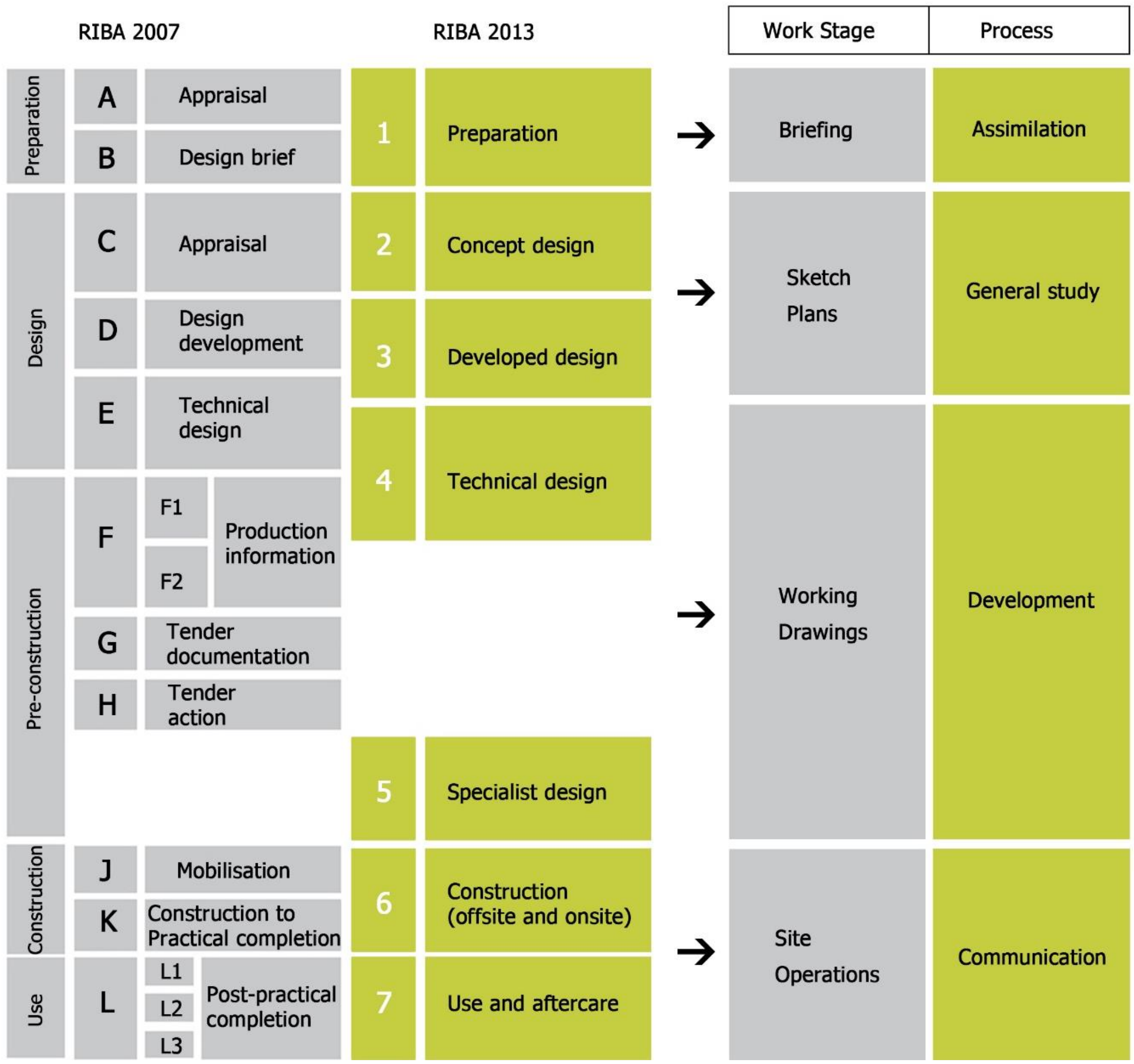


Fig. 6.4-6: The RIBA Outline of Work for exhibition design process.

Source: Adapted from the RIBA 2007/2013 Outline Plan of Work, edited by author

As shown in **Figure 6.4-6,** each phase in the chart is interpreted differently, as each is formed to the requirements of the given work processes. It is assumed that the architect is responsible for conducting the overall design process and leading the project team, and therefore, two major functions - design and management - are combined (Newton, 1995). This design model establishes a workable sequence of exhibition design stages that can be adopted by museum designers for conducting the exhibition project. Moreover, RIBA project plan seems to imply that the process in a strongly linear process, and it identifies several stages in briefing; that process is to be overseen by a 'project steering group' which will establish 'the vision and key performance indicators'. Particular care and sensitivity is needed in following this work process. However, there's little mentioned about anticipating technological advances or mapping out future technology in the RIBA documents, as Lin mentioned in the thesis, the RIBA project model may only depict the work stages in a design project in which decisions are made, it is not a model of creative method (Lin, 2014).

Apart from *British Standards 7000* and *RIBA Outline Plan of Work*, there are more descriptive models focus on museum theories or deal with planning museum programmes. **Table 6.4-7** is a comparison of museum exhibition design contexts developed by different authors through history, which indicates that the published museum exhibition design processes show a number of stages. Such stages imply that as design work progresses, potential solutions and decision points can be presented to the project team at appropriate stages of planning and design.

Exhibitions: Planning and Design Klein, L., 1986	**Exhibitions in Museums** Belcher, M., 1991	**Museum Exhibition Theory and Practice** Dean, D., 1994	**The Manual of Museum Planning** Lord, G. D. And Lord, B., 1999
Planning phase Research or data collection. Statement of goals. Concept or thematic development. Preliminary space plan. Presentation and construction.	**Preliminaries** Problem analysis Feasibility / Programming Research Analysis	**Conceptual phase** Product-oriented activities. Management activities.	**Museum planning** Preliminary planning. Corporate plan. Collection analysis and strategy. Market analysis and strategy. Public programme plan. Feasibility study.
			Briefing Functional programme. Technical specifications.
Design phase Preliminary design. Secondary design Final design.	**Design development** Communications Synthesis	**Development phase** Planning stage. Production stage.	**Design** Schematic design. Detailed design.

Documentation.	Design revision		
Design production phase Final design. Bidding and selection of contractor. Completion of the design production.		**Functional phase** Operational stage. Terminating stage.	**Construction documentation** Tender action Contract negotiation
Supervision of construction phase **+** **Ongoing construction phase**	Monitoring Evaluation	**Assessment phase** Product-oriented activities. Management activities	**Construction** Commissioning

Table 6.4-7: A comparison of published museum exhibition design processes

Source: Adapted from *Exhibitions: Planning and Design* by Klein, L. 1986; *Exhibitions in Museums* by Belcher, M. 1991; *Museum Exhibition Theory and Practice* by Dean, D., 1994 and The Manual of Museum Planning by Lord and Lord, 1999.

To compare the nature of these three models, the Klein, Belcher and Dean Model can be described as covering design purposes at project level from the museum designers' point of view, whereas Lord and Lord's model presents an overview of museum programme planning rather than designing museum exhibitions. As such it is for management and planning purposes at museum organisation level. However, none of these three models consider interdisciplinary co-ordination and there is a lack of inter-relationship between design tasks except in chronology. The design process here should address design objectives based on curatorial roles in a systematic way, and it is essential to anticipate technological advances and plan how they might be harnessed in the early stages of the project.

6.5 Conclusion

This chapter provides a bridge of interconnecting theoretical findings with practical process for museum exhibition design. The first part of the chapter combines visitors' motivations and expectations with their identities and participations. Based on research from Falk, the author noticed that people make choices about what to do with their leisure time based on the ability of these activities to fulfil personal needs, desires and lifestyles, which includes psychological needs, educational needs, social needs, relaxation needs, physiological needs and aesthetic needs (Falk, 2009). And all these needs are represented when asking visitors about their reason to go to a museum. Again, according to Falk and Dierking, the museum environment can be best described as a mixture of personal, physical and socio-cultural contexts (Falk and Dierking, 2000; Falk, 2009). In this museum visitor experience model, the visitor's identity is essential, and their identity-related needs are made visible through visitor's motivations/expirations.

The second part of the chapter reviews interactive exhibits which are objects which can influence (in shape or in content), by involving themselves at the sensory, intellectual and/or emotional level, in order to understand real phenomena and/or learn about museum items. It also looked at the impact of interactivity inside science museums, mainly based on Andrea Witcomb's researches, attempts to both understand and explain the contemporary debate surrounding the changes in interactive exhibition and museum practices.

The last part focuses different descriptive and prescriptive models for exhibition design process, which included the *British Standard 7000* and the *RIBA 2007/2013 Outline Plan of Work*. Although these models are concerned with planning and design programmes, they are not specifically for museum exhibition design. However, from those reviews, the proposed design framework should be capable of being adapted to organise complex museum exhibition projects, enable communication, and understanding between different design disciplines and diverse professional.

From Chapter 3 to Chapter 6, a completed theoatical foundation for this study has been developed, as it is shown in **Figure 6.5-1**. This analytical overview of the significant literature published on the topic, which combines the key conceptual, methodological and practical issues summarised together as the theoretical background of this PhD research. After that, the thesis presents its discrptive research and experimental research based on case studies and design-based experiement.

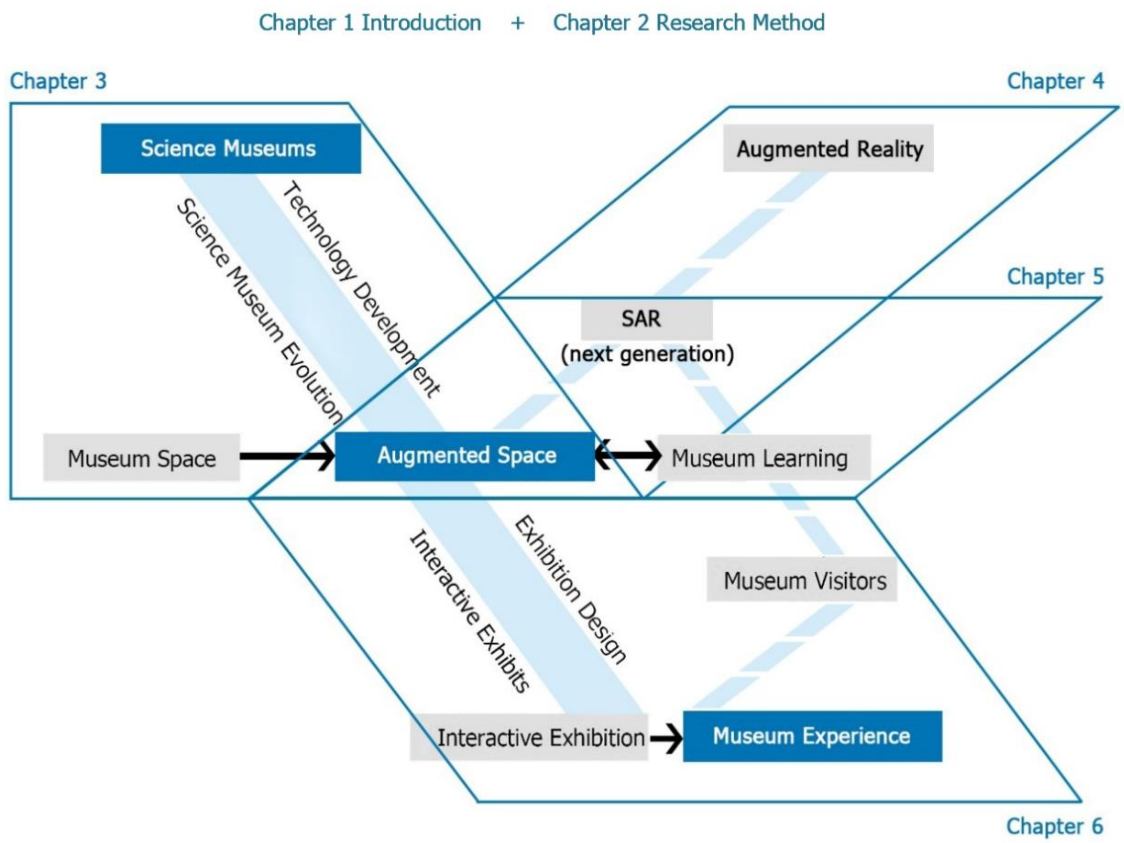
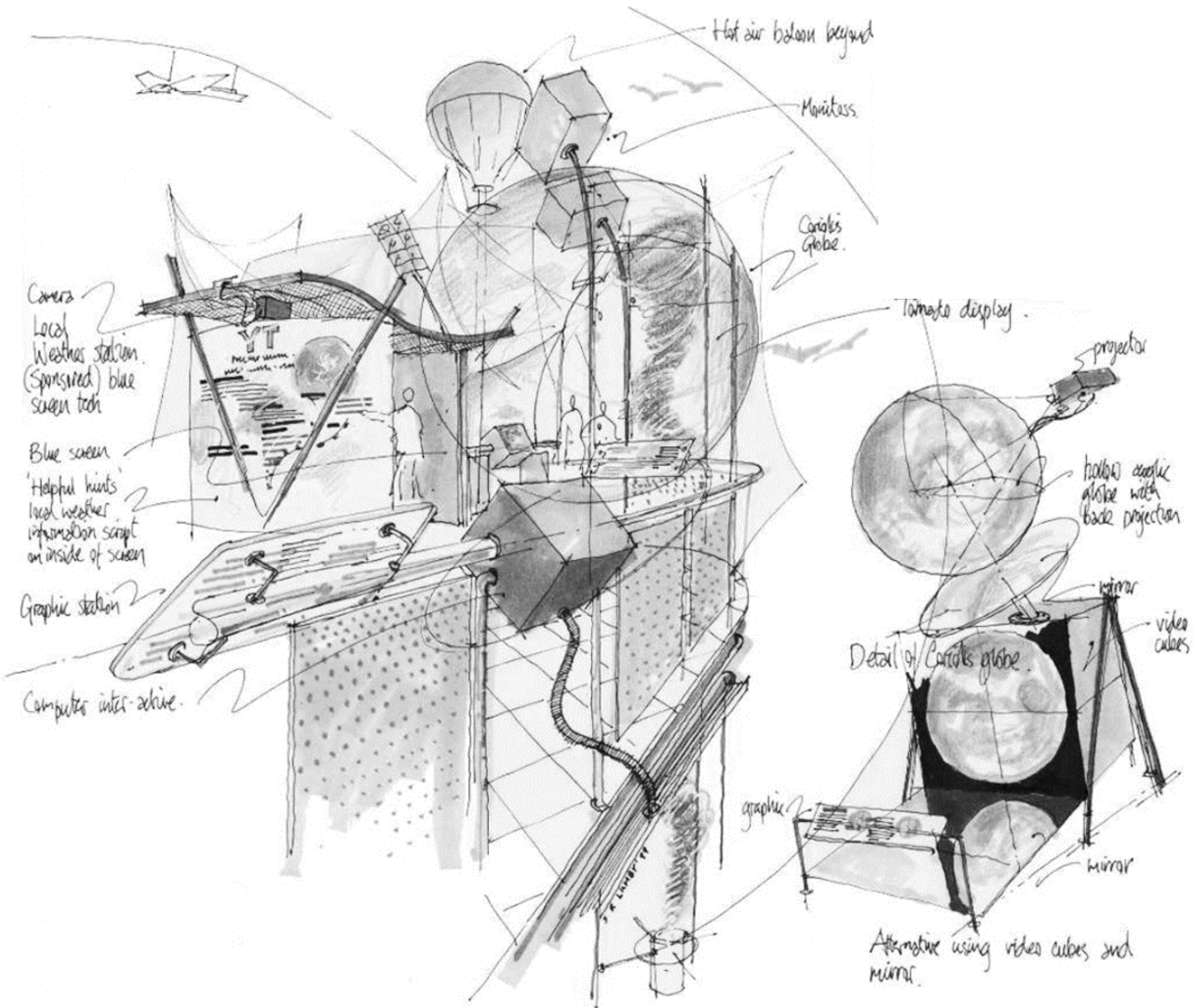


Fig. 6.5-1: A summary of the main theoretical foundation (Chapter 3 to Chapter 6) of this PhD study.



Chapter 7.

Case Studies

Figure: Air Pavilion, the Magna Science Adventure Centre, illustrated by the author

Chapter7. Case Studies

7.1 Chapter Overview

The aim of the case studies in this research was to explore two example of application of augmented technologies in the practice of museum planning, in order to understand the relationship between physical space, digital technology and narration on the basis of these two elements. In this chapter, case analysis is undertaken in conjunction with results and suggestion from previous chapters to produce compositional threads and design sensitivities for developing augmented space in the realm of practical or actual experience. Each of the example concentrates mainly on the following issues:

- Through the desk research to obtain an understanding of the design background / context of the museum case.
- Through tender document analysis and informal interview with museum designers, to draw out the guiding concept of the exhibition inside.
- Through field study (mapping/space syntax/observation) to obtain an understanding of the physical setting and narrative of the gallery.
- Through analytical studies to gain an understanding of the use of augmented space and the communication of the exhibition's messages.

These issues entail an examining of the context and messages on site using specific observation criteria, and comparing it to the information from the semi-structured interviews about curatorial intent from people who were involved in the process of constructing the exhibition narrative. Starting from the previous literature review on museum experiences, the author believes that the good augmented applications developed to enrich the museum narration should support collaborative (social) rather than individual use to the greatest extent possible, in the interest of learning outcomes as well as enjoyment. By investigating how the current setup in two museum galleries, the choice of augmented technologies, this chapter amplifies the narrative by determining the correlation between the complexities of physical setting, digital media and ways of spatial augmentation with the educational ideas of exhibition message, constructivist learning and interactive experience.

7.2 Case Study 1 - Air Pavilion, Magna Science Adventure Centre

7.2.1 Museum background and context

Fig. 7.2.1-1. The location of the MAGNA Science Adventure Centre

Source: Google Map (Accessed 15/08/2014)

MAGNA Science Adventure Centre (Abbreviated as MAGNA) is located in Rotherham, the north of England (**Figure7.2.1-1**). The former building of MAGNA was a melting shop called the Templeborough Steelworks, opened in 1917 to produce steel for artillery shells used in the First World War, and it was once the largest electric melting shop in the world and the site’s industrial history stretches back to Roman times (Jepson, 2017). Now, the surrounding cogging mills and cooling beds have been demolished, leaving the melting shop standing in its enormity, as shown in **Figure7.2.1-2**, the structure was nine storeys high, with the main building formed of two 350m long bays containing 14 open hearth furnaces (Cutler, 2017). This huge architectural space provided great potential for refurbished work.

Fig. 7.2.1-2. Templeborough Works, Sheffield Road

Source: United Steel Companies Ltd. www.picturesheffield.com & Grace's Guide to British Industrial History[10]

The survival plan for this remarkable architecture was outlined in 1995 (Hamshere, 2003). In the very first proposal, it highlighted the aim of this renovation project, which was "not just offer a place where people come to admire and marvel at the achievements of the past, but this museum should also be alive, showing what is being achieved today, and having a relevance to the future" (Event Communications, 2001). Those key words as 'achievements of the past', 'being achieved today' and 'relevance to the future', also defined those key strategies of the project: 1) To create a sustainable and long living museum that will be a major leisure and educational destination; 2) To represent pride in past achievement; 3) To be a showcase for local industry and remarkable innovation, 4) To act as an inspiration for future generations to continue the tradition of technological advance, and finally 5) To foster industrial change and enterprise by introducing the value of science education through immersive exhibitions.

With those aims, a set of objectives was derived encompassing the science museum activities of interpretation and education; with a particular focus on children in educational groups and in families, in addition with an independent educational charity at the helm. In 1998, the building was transferred to the MAGNA Trust, which brought the whole project back into a new stage, the renovated project was designed

[10] Grace's Guide is a free-content not-for-profit project dedicated to publishing the history of industry in the UK and elsewhere. Its aim is to provide a brief history of the companies, products and people who were instrumental in industry, commencing with the birth of the Industrial Revolution and continuing up to recent times.

by leading architecture firm - Wilkinson Eyre Architects and it was soon completed after 3 years' construction, opened its doors to public in 2001. MAGNA has received a number of awards since then, especially for the innovate transformation of a redundant steelworks to create the UK's first science adventure centre. The most remarkable award was the RIBA Stirling Prize[11] on 20th October 2001 (Welch & Lomholt, 2011), for showing "high architectural standards and substantial contribution to the local environment" and "allow the existing building to speak for itself" (Wainwright, 2001). This project beats six other short-listed entries, among them the much-touted Eden project in Cornwall, the British embassy in Berlin and Parliament's Portcullis House extension in London.

It was not an easy win, because the massive volume of the building, as Martin Spring stated in the article "Phoenix of the North" in 2001 (Spring, 2001):

> "…step inside the architecture, you find yourself in a cavernous and gloomy hall. After the first gasp of awe, it still takes a minute or so for the unprecedented vastness of this building to sink in. The great hall stretches 350 m in length, so far in either direction that you can barely see the two end walls through the gloom…"

In dealing with the old industrial typology, the project team of Wilkinson Eyre Architects made the structure stand out from other industrial-cultural conversions and accomplished this by doing little to the inside of the building, they decided to let MAGNA makes full use of those two 350 metre long and 35 metre tall bays which form the building. The pin holes of these bays allow light to penetrate into the dark interior, and indicates the nine storey high transverse aisles, form the entrance to each attraction/pavilion. Within this space are artefacts from the original steel making process, retained as sculptures of the past. The steel structure in the main building has been retained, displaying rust, scorch and heat marks representing the buildings past (Anon, 2015).

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[11] The RIBA Stirling Prize is the UK's most prestigious architecture prize. Every year it is presented to the architects of the building that has made the greatest contribution to the evolution of architecture in the past year.

The main focus for Wilkinson Eyre Architects was how to represent those achievements of the past, and make it relevance to the future. Four separated exhibition galleries have been finally included in this space were all relate to the steel making process through the Aristotelian elements - Earth, Fire, Water and Air. All these four themes are connected by steel walkways and bridges, in keeping with the past industrial use (Mimoa, N.D). There is also an area where visitors can see part of the steel making process named as 'The Big Melt' (**Figure7.2.1-3**), which emphasises how the building would have been used and celebrates Sheffield's industrial past.

Fig. 7.2.1-3. The Big Melt feature at MAGNA in Rotherham

Source: www.visitmagna.co.uk/content/273/press-media , Accessed 15/08/2015.

As great reminders of Britain's heritage, whilst the majority of the steel factories and coal mines have been destroyed, this melting shop remains intact, and transformed into a science centre, stands as testimony to a bygone industrial age (BBC N.D), uses a new framework of its previous life to provide a window to the future world.

7.2.2 Guiding concept of the internal exhibition

From the background introduction, we notice that instead of looking backwards at a dead industrial process, the museum curators want to use the original architecture as a "backdrop" for a brand new, forward-looking science discovery centre (Spring, 2001), and to echo with the rich industrial heritage of steelmaking industry in a poetic way – four natural resources (Earth, Fire, Water and Air) celebrated at the MAGNA today are not only used to manufacture steel products which were shipped around the world; they were also four fundamental elements once defined by Aristotle, and made up all matter and were the cornerstone of philosophy, science and medicine for two thousand years (BBC N.D). Additionally, these four elements also align with the four states of matter that modern science has agreed on, which are solid (earth), liquid (water), gas (air), and plasma (fire). Based on that, the design team limited the subject matter to the four classic physical elements and devoted a pavilion to each, these four presentations are real rather than virtual, and have been conceived as 'adventures' into the physical phenomena of the elements, many of them encouraging hands-on participation (Spring, 2001).

Inside the vast building, the MAGNA experience can be divided into six parts in total – there's four architecturally stunning and gadget-packed pavilions and two multimedia shows. The planning places four pavilions in different levels of the building, connected by new steel bridges and walkways. Each pavilion was designed to relate to its specific theme (**Figure7.2.2-1**): The earth pavilion is constructed of solid steel plates reminiscent of tectonic plates, which located in the basement below the ground slab. The Air Pavilion, meanwhile, is conceived as a dirigible airship enclosed in translucent cushion fabric and is hung high off the ground within the roof space. The water pavilion is a stainless-steel vessel sitting on the ground slab, and the fire pavilion, at the end of the space, is a black box suspended from the main structure. Although the existing steel-making building and the processing plant retrained for the refurbishment, which resulting in a very gigantic empty space, these expressive forms still successfully combined to create a coherent and self-contained composition within it. Four new partitions house the theme-related exhibits and provide separate environmentally controlled conditions.

According to the book Bridging Art and Science by Wilkinson Eyre, he explained the guiding concept of this project, "The location, form and construction of these pavilions relate to the respective elements and, together with the artefacts retained from the steel-making processes, combine to make a new composition." (Wilkinson & Eyre, 2001).

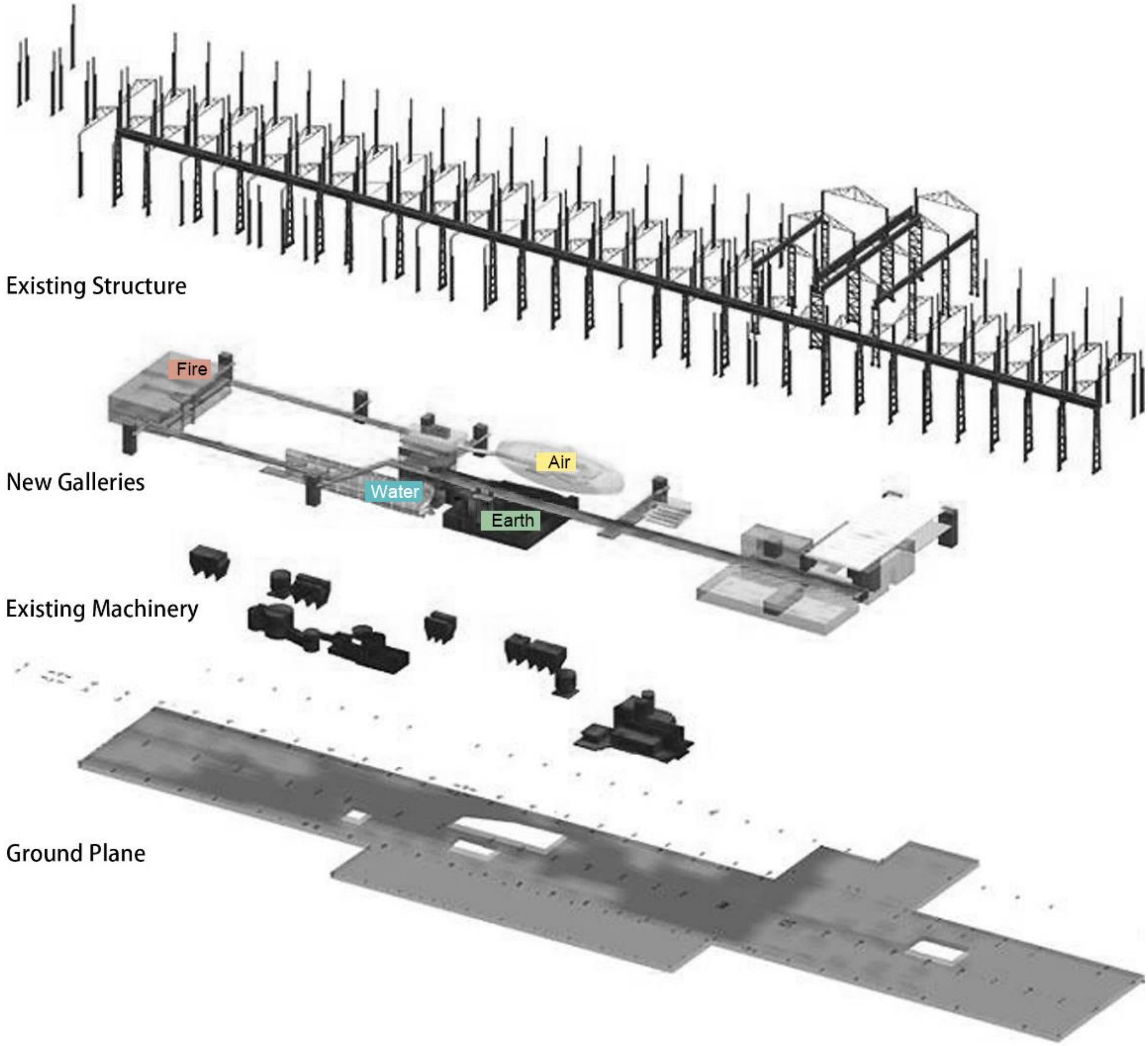


Fig. 7.2.2-1. Exploded isometric drawing of the MAGNA

Source: Provided by Wilkinson Eyre Architects, edited by author

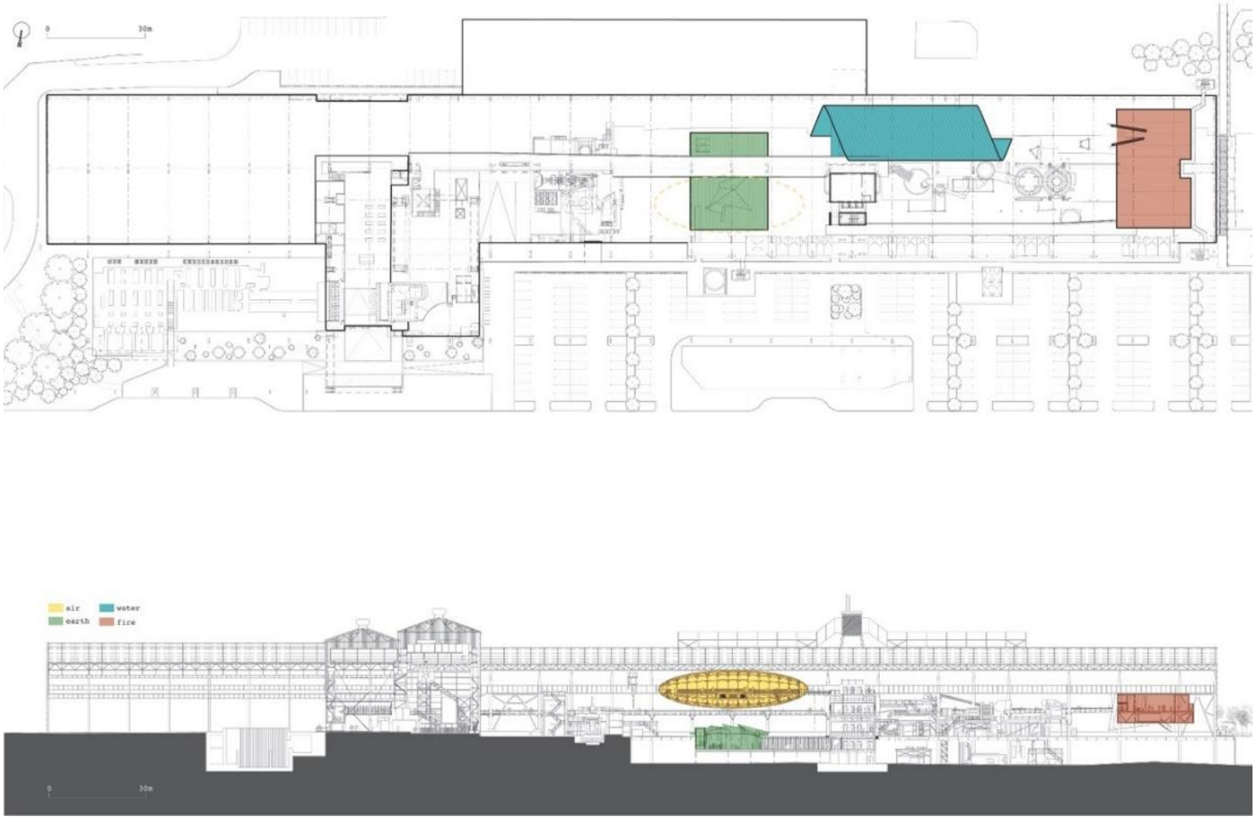


Fig. 7.2.2-2: Plan and section drawing of the MAGNA, four themed pavilions are highlighted in different colours on both drawings. Colour yellow represents the Air Pavilion, colour green appeared here as the earth pavilion, colour blue stands for the water pavilion, and finally colour red indicates the location of the fire pavilion.

Source: Provided by Wilkinson Eyre Architects, edited by author

This 'memorial' architecture with dead industry is replaced with new pavilions devoted to the future science, the new planning have played up the darkness and vastness of the space and created a theatrical effect through various of lighting effects, and the dominant lighting effect inside the building, is an eerie scarlet glow radiating from the flank wall is designed by Speirs and Major[12], where the original metal cladding has been replaced in scarlet glass-fibre profiled sheeting (Spring,2001). Inside the gloomy shed, the primary

[12] Speirs and Major is a UK-based, multi-award-winning design practice that uses light to enhance the experience of the visual environment.

background lighting is a low level monochromatic red, suggestive of both rust and hot molten steel smouldering in the dark interior, against which the individual pavilions shine, as shown in **Figure7.2.2-3**.

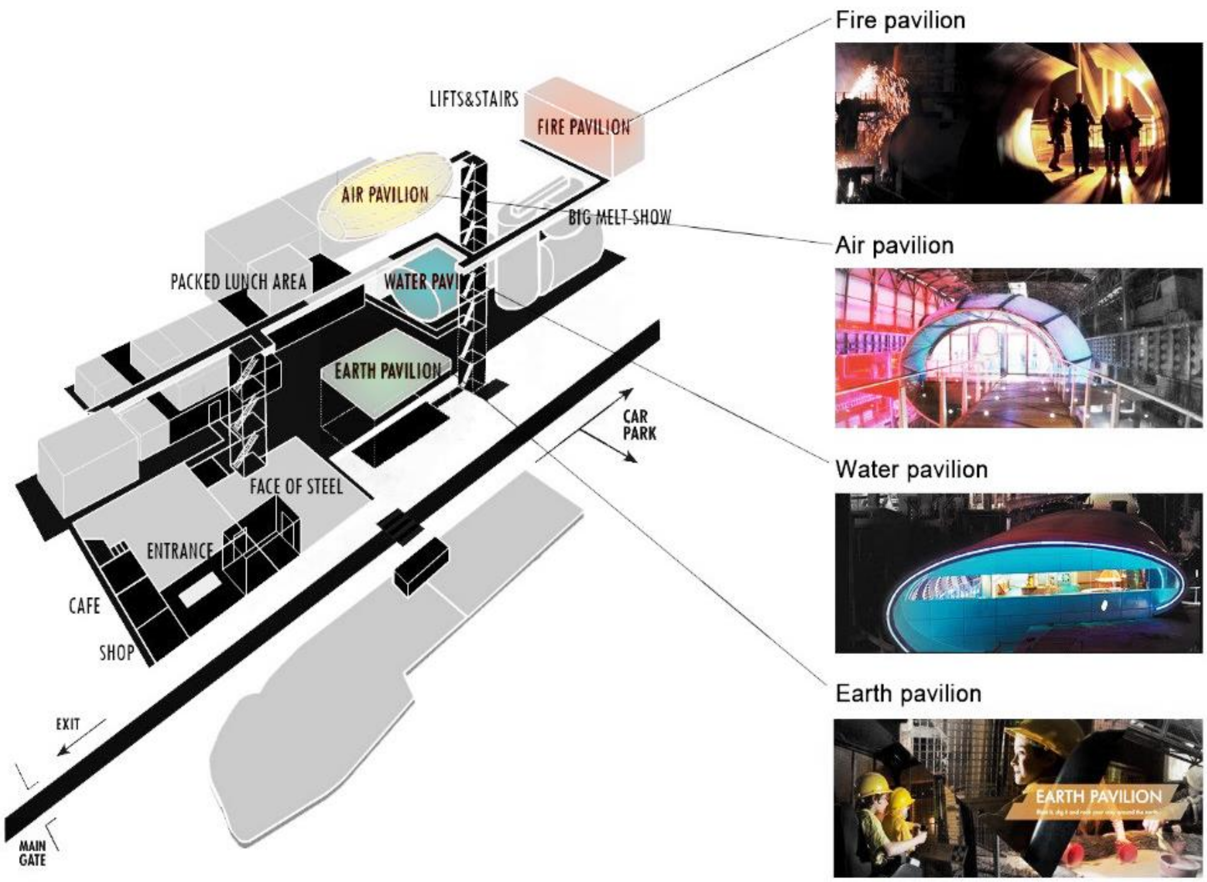


Fig. 7.2.2-3: The lighting effects for four pavilions inside the MAGNA: the architecture is part of the exhibition - exhibition is part of the architecture, architecture is part of the exhibition.

Source: Edited by author

With the aim of attracting young audiences to this non-traditional science centre, apart from the architectural space it is more essential to create innovative narrations with immersive augmented space. Event Communications[13] and the chief curator Stephen Feber quickly embraced with digitally-enhanced technologies for sensory experience in gathering and disseminating scientific knowledge inside the massive

[13] Event is Europe's leading exhibition design group, recognised as a pacesetter in the field of museum and attraction design, and they formed an exhibition design team for MAGNA project.

architecture and make digital overlay on the physical form. They believed that augmented space would contribute and extend the exhibition experience beyond the old dark steel factory space and create knowledge in the realm of experience and affective information, however, it demands innovative methods and carefully constructed spatial stories.

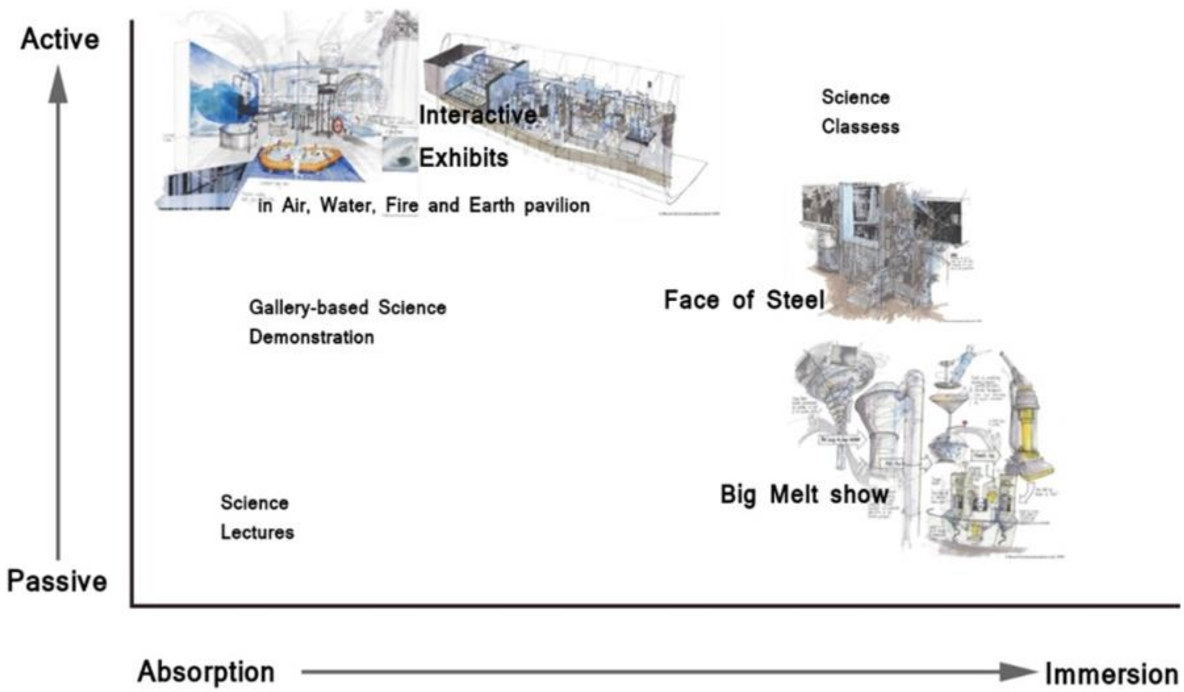


Fig. 7.2.2-4: The Experience Realms Model of the MAGNA

Source: Adapted from, Pine II and Gilmore 1999: 30, edited by author

With the aim to attract children and younger visitors, renowned education experts, curators, architects, museum coordinators worked together to create new environment inside each pavilion. Those exhibition galleries involve a high degree of immersion in direct inquiry-based, hands-on activities and particular science topics which related with four themes. According to the typology of experience realms[14] by Joseph

[14] Pine and Gilmore (1999) conceptualised four realms of tourism experiences with fluid boundaries. Experiences were described based on their position on a vertical pole where one end point was active participation and the other was passive participation and on a horizontal pole with absorption on one end and immersion on the other, which is the typology of experience realms.

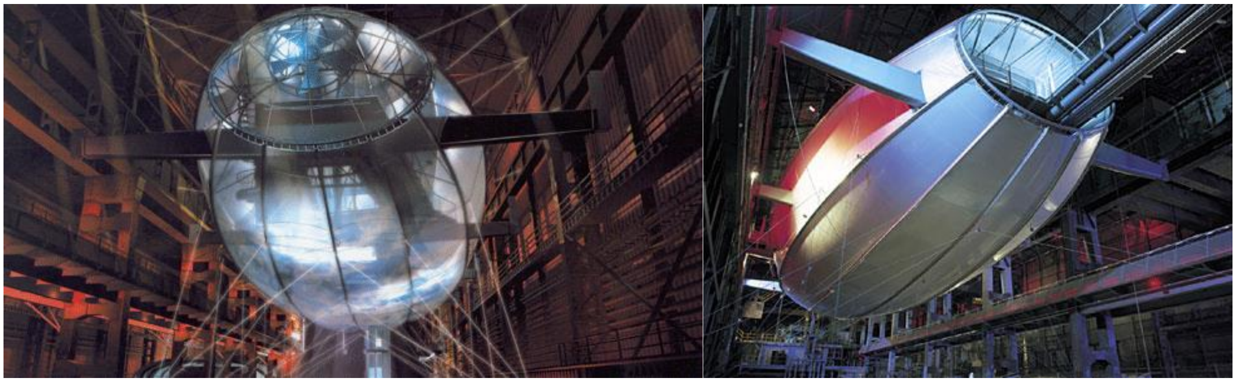
Pine and James Gilmore, the experience of the MAGNA can be distinguished by two axes of experience; one that indicates the degree of participation (from passive to active) and one that indicates the connection of the visitor to the experience (from absorption to immersion). The result is a four-fold model: active-absorption is education; passive absorption is entertainment; active-immersion is escapist; passive-immersion is aesthetic (Pine and Gilmore, 1999). For this brand-new science centre, four interactive themed pavilions represented the active-absorption elements, as shown in the diagram above (**Figure7.2.2-4**). Activities inside four galleries have generally received positive feedbacks, and appear to have educational benefits which involving kinaesthetic explorative, contextual conceptualisation and knowledge-challenging stimulus, these gallery space provide sufficient freedom to create immersive and interactive scenarios that can also facilitate educative outcomes.

7.2.3 Physical setting and exhibition narrative

The following subsection provides detailed insights on the Air Pavilion, as it is the "most spectacular" structure inside the MAGNA (Spring, 2001) and the most popular gallery according to visitors' feedback (Anon, 2015). The gallery is designed as a huge dirigible which seemingly floats in the space. Before approaching it, the visitors have to first step into the dark dramatic atrium and climb up those labyrinthine stairs, which feels like walking onto the set of a giant sci-fi movie with the sounds, atmosphere and special effects inside. When the visitors reach the main walkway within the heart of the building, their attention will be attracted by this glowing translucent airship that floats structure[15] beneath the steel sheet roof, tethered by steel cables to the massive existing steel column, as **Figure7.2.3-1**. The 'Zeppelin' structure is surrounding by a classic cigar-shaped membrane, 44m long, 18m wide. The traditional canvas skin has been replaced by three layers of translucent ETFE fritted with a film of silver dots. And the pavilion glows with a blue hue and gently drifts with rolling clouds, with configurations that tend to be freed from

[15] Because the structure is clipped to aluminium extrusions held in position with a cable net tensions, it gives visitors the impression that it is floating.

constrictions and characterised by multiple layers of transparent materials, establishing a continuous relationship between its interior and exterior.



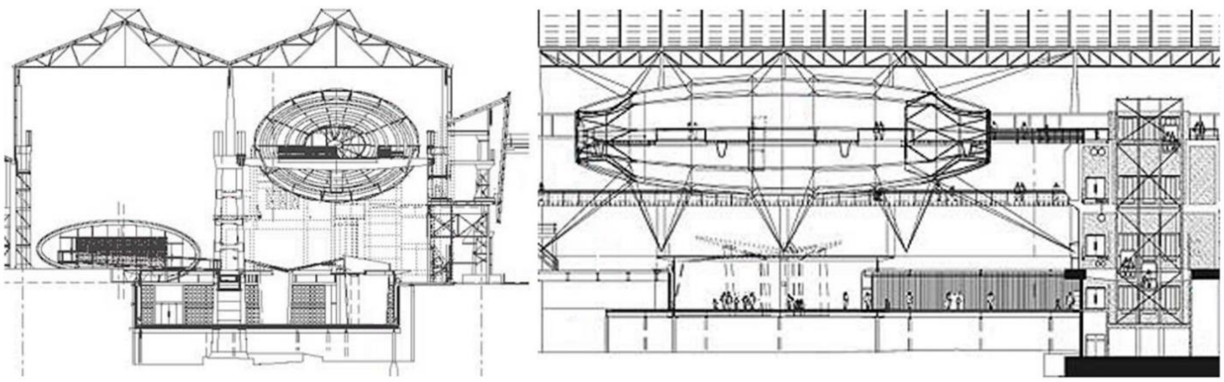


Fig. 7.2.3-1: Two Cross sections of the Air Pavilion

Source: Demolition drawings from Wilkinson Eyre Architects, accessed 15/11/2014

The exhibition inside the Air Pavilion is strongly related to the theme. The exhibition settings under study is a simple oval-shaped open plan, as shown in the plan layout (**Figure7.2.3-2**). There are 20 scientific exhibits in total inside this Air Pavilion and it has been designed as a high-tech exhibition involving latest AR techniques. As it is shown on the diagram, a small group of individual exhibits set along the axis of the gallery, others are located against the perimeter boundary of this oval-shaped gallery space, or against the main structural elements, which is designed to encourage a peripheral approach or a directional approach within this augmented space.

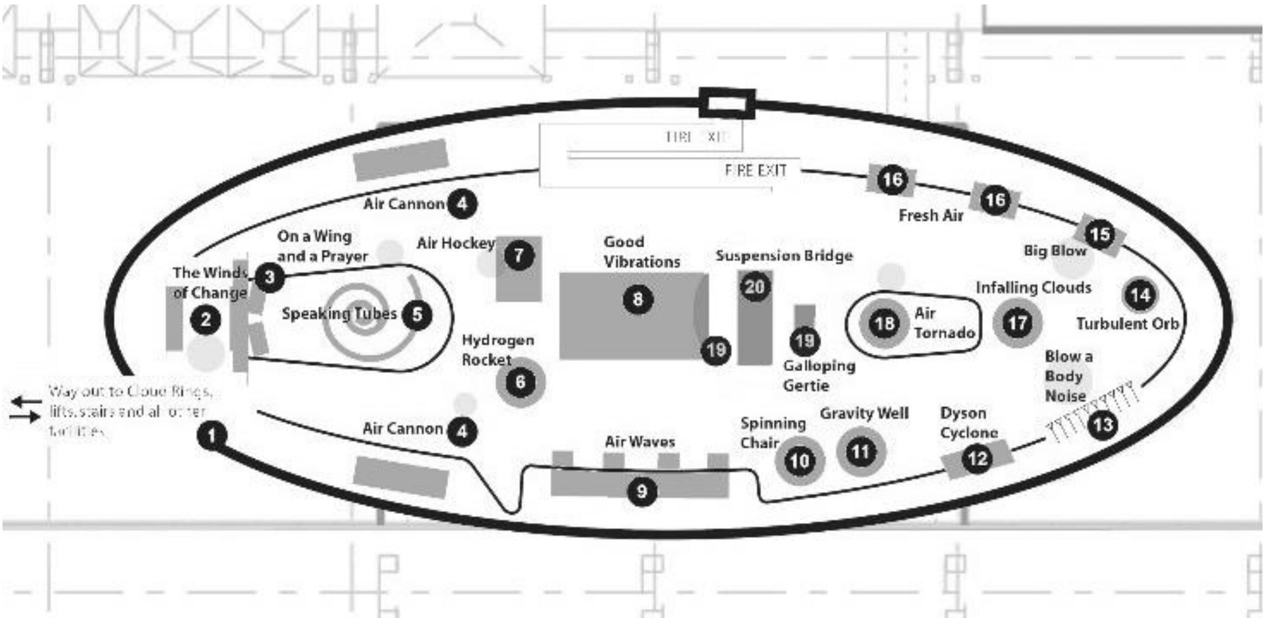


Fig. 7.2.3-2: Exhibition floor plan of the Air Pavilion

Source: Plan of the Air Pavilion (www.visitMAGNA.co.uk/education/resources), accessed 15/11/2014

According to the paper 'Exploring, Engaging, Understanding in Museums', Wineman et al. claim that "pattern of accessibility through the space of museum exhibits, their arrangement in groups, or the separation between each other have impacts on how a museum is explored by the visitors; the extent it engages with the surroundings and the level of understanding it shapes" (Wineman, Peponis, & Dalton, 2007). Moreover, the geometric relationships of gallery space and the topology of all these exhibit layout impact visitors' wayfinding, as visitors understand their location within the floor plan, they will also understand the location of the whole narrative structure that the curator trying to present, as it has been mentioned by Weisman, Werner and Schindler, they mentioned, a space design is successful if it is legible (Weisman, 1981; Werner & Schindler, 2004).

The spatial typology of the Air Pavilion is an open plan with configurations that tend to be freed from constrictions and characterised by multiple layers of transparent materials, establishing a continuous relationship between interior and exterior. The space syntax analysis were adopted here takes into account two different properties: permeability, as the spatial network created by accessible space, and visibility, as the set of visually interconnected space, either directly or through transparent material, are impacting visiting experience inside.

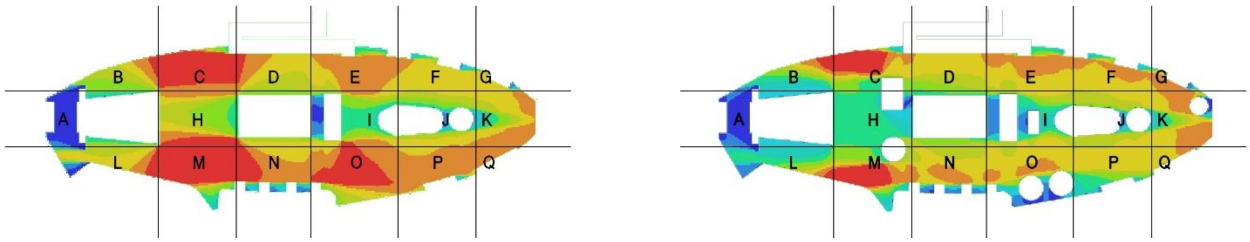


Fig. 7.2.3-3: Visibility (Left) and Permeability (Right) through VGA analysis.

Through VGA analysis, the visual connectivity graph (**Figure 7.2.3-3 left**) of the Air Pavilion is generated at the eye-level, which includes the all visually accessible areas in the analysis. It demonstrates that the regions with the highest degree of visual connectivity are at region marked C and M, which are symmetrical by the long axis of the ellipse plan. Both of these two regions separated from direct visual interacts with entrance area with same one exhibits. This demonstrates the visitors have great visual access to the exhibition space after just walking through the entrance area, zone A. The second tier of the high visibility area is symmetrical by the long axis too, occupying zone O and E. They do not have direct visual interacts with entrance area as well. As for the lowest visibility area is located at the entrance. And other areas have low visibility are located between each exhibit.

The knee level of the VGA map, indicates that at the permeable level of the gallery (**Figure 7.2.3-3 right**), the high connectivity value is distributed at the same area which enjoys high rated visibility. The highest value of permeability is also situated within zone C and M, along with the perimeter. However, these areas are much smaller than the zones have high visual connectivity. Less than half of the high rated visual connectivity area is overlapped with high permeability zone.

These analyses indicate in those exhibition areas like C, M, E, O; museum visitors are exposed to an unobstructed overview of the gallery's core bringing to the foreground visitors' experience, and a continuously open interior might be programmatically subject to attractiveness. In the meanwhile, because of the higher permeability, visitors in these areas tend to interact with exhibit quickly and move to another one, this is because of in continuous surveillance by other visitors, it seems impossible to concentrate for a long period of time. On the contrast, exhibition area like A and I, which with a low-level of visibility and permeability are, in fact, where the in-depth interaction and the majority if informal learning is produced, exhibits in A and J have longer holding power, and higher visitor engagement levels. In these cases, low permeability and visibility values seems to create a sense of freedom, spontaneity and informality in the use of space, which offer an opportunity to 'escape' from the continuous presence of visitors. The augmented space in A and J seem to enable a more malleable relationship between exhibit, space, the self and others.

The observational study – movement flows (as shown in Appendix A.1) reveals similar levels of integration inside the Air Pavilion. A higher influx of visitors is perceived in area A and I, comparing with other zones of the gallery. The augmented space within the zone A contains the exhibit - *Winds of Change*, which is defined by the curator as the 'introduction' of the Air Pavilion. With the wind simulator, visitors can feel different wind force scales. With the wind force scale increased, the speed, shape, and colour of projected clouds and sky change rapidly. Then, four times an hour, the noise reaches a climax with a thunder storm, the strongest winds are accompanying by light and sound effects throughout the Air Pavilion, after which the calm returns, and the crescendo begins again. In the meanwhile, the augmented space in the zone I is the feature exhibit of the pavilion, open inquiry and examination are probed in the concept. It contains an Air Tornado simulator, and it is an example of exploration as task activity. It consists of a tower that is constructed with thick disks at either end and has four posts between them. The bottom disk has a grill through which smoke emerges and each post has a fan attached to it. As the smoke rises from the base, the fans on the posts swirl it, eventually creating a large air tornado. As the exhibit is completely open and unrestricted, visitors are able to directly touch and manipulate the smoke, even walked through. Visitors' explore the effects of disturbing the air patterns between the posts, and as they do so, they change the shape of the tornado. The augmented space design for air tornado experience will be discussed in more detail in analytical studies at the end of the chapter.

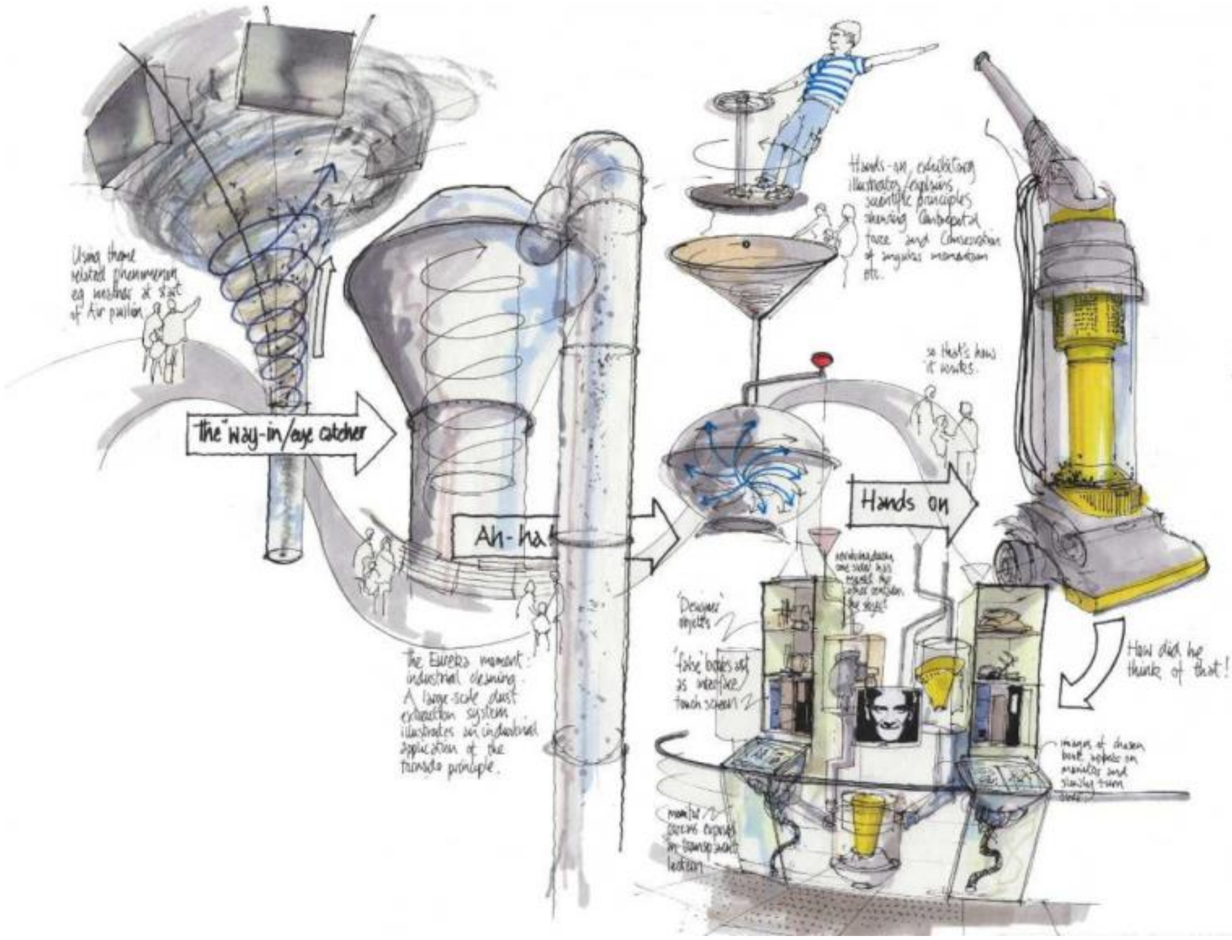


Fig. 7.2.3-4 The exhibition narrative of the Air Pavilion, it begins with the exhibit - Winds of Change and went through an array of exciting, hands-on, air-themed activities.

Source: illustrated by the author

7.3 Case Study 2 – Futures Gallery, Thinktank Science Museum

7.3.1 Museum background and context

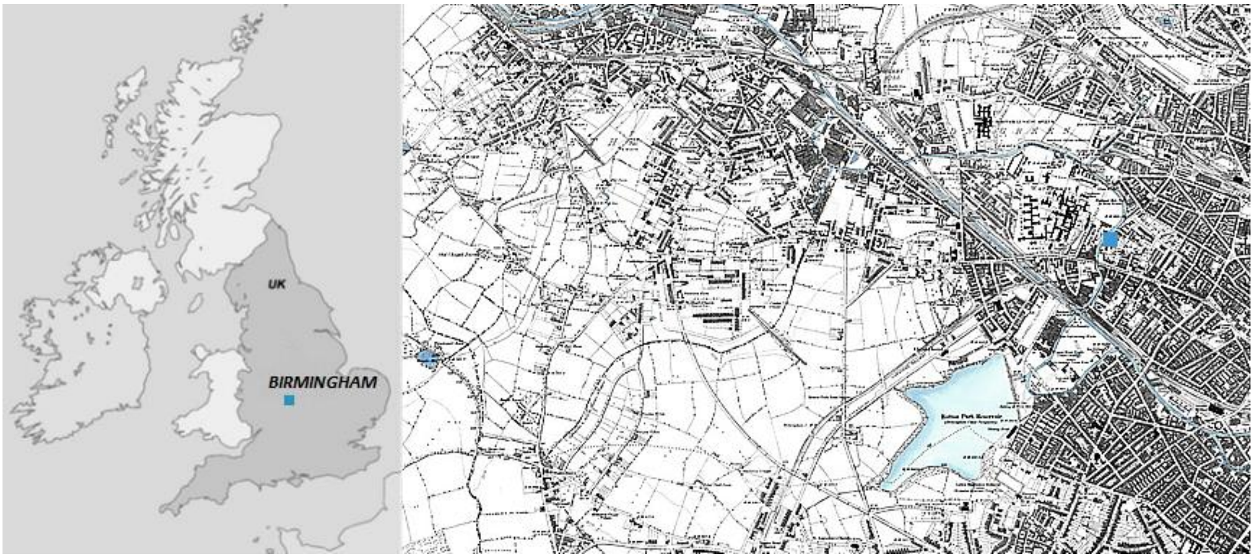


Fig. 7.3.1-1. Those blue dots indicate the location of the Thinktank, Birmingham Sciecne Museum.

Source: The location on the schematic map of Birmingham UK 2012, edited by researcher

Thinktank Birmingham Science Museum (Abbreviated as THINKTANK) is located inside the Millennium Point building, which was regenerated from a 12-acre brownfield site. The surrounding area is a mix of recent developments, and the area is constantly evolving and the introduction of the HS2[16] station has brought further activity and improve connections. The mission of the Millennium Point is first signed off by the Millennium and Charity Commission[17] in 1999 ("Our History, Millennium Point", N.D.), to provide activities aimed at developing the technological base of the region. The purpose of this complex building is primarily educational, as the management department of Millennium Point[18] explained, "The project enabling a great

[16] HS2 - High Speed 2 is a planned high-speed railway in the United Kingdom linking London, Birmingham, the East Midlands, Leeds, Sheffield and Manchester

[17] Millennium and Charity Commission is also known as the Millennium Commission, it's a United Kingdom public body, was set up to celebrate the turn of the millennium. It used funding raised through the UK National Lottery and it awarded £2.7 billion of Lottery money for projects to mark the new millennium, which includes the Eden Project, Tate Modern, National Botanic Gardens of Wales and National Space Centre.

[18] Millennium Point in Birmingham is England's largest landmark Millennium Project outside London and, since opening, has welcomed more than 1 million people through its doors each year.

place to experience the future." adding that it was, "founded as a destination for science, technology and learning... By exploring ideas and concepts, highlighting and demonstrating innovation" (Foster & Demidowicz, 2005). Millennium Point acted as a prominent building in this important quarter identified as an area of transformation in the big city plan.

This architecture was designed by Grimshaw Architects[19] and built at a cost of £114 million, which includes £50 million of Millennium Commission lottery funding and £25.6 million from the European Regional Development Fund ("Start - Millennium Point", 2010). The Millennium Point Trust and Grimshaw partners are committed to creating a high-quality work of architecture that will be recognised easily, and reinforcing the scheme's status as a landmark project, within Birmingham and over a much wider constituency. The rigour of this approach will extend from the external landscaping and urban design right through the interiors and the design of the exhibition.

The building has a T-shaped floorplan, with the THINKTANK and a technology innovation centre in the section of the building facing Curzon Street. The other main section of the building extends northwards towards Jennens Road, this part of building contains the Hub, which is intended to act as a focal point and meeting place for people using different facilities within the development. The scheme's compact built form allows the necessary physical connections between the three major components and creates a suitable density of use internally. It also gives the building the physical density characteristic of city centre public landmarks. The organisation and landscaping of the site is designed to draw people into the Hub, it has been act as an entrance from the north and the south approaches as well as connecting to car park, giving visitors a clear destination. The fact that people will be arriving at the Hub from a number of directions at various levels will be used to create an open, multi-level facility that will lead people in to the science centre – THINKTANK, and Technology Innovation Centre (TIC). The free-form shape and distinctive structure of the space reinforce its status as the focus for the site and contrast with the leaner arrangement of the

[19] Grimshaw Architects (formerly Nicholas Grimshaw & Partners) is an architectural firm based in London. Founded in 1980 by Sir Nicholas Grimshaw, the firm was one of the pioneers of high-tech architecture.

THINKTANK and TIC. The Hub will also face outwards, to provide views out from the highest levels linking back to its location in the city.

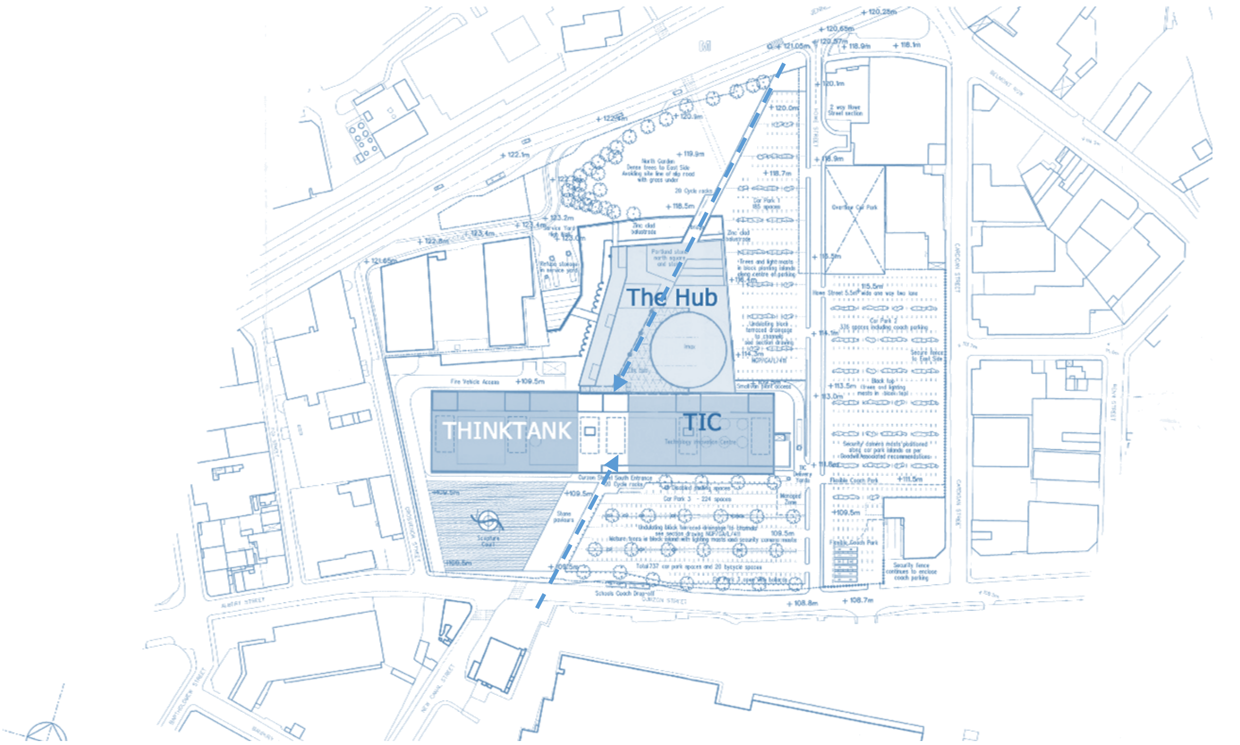


Fig. 7.3.1-2. The design of the development brings together the three main elements of the Millennium Point project – THINKTANK, TIC and the Hub, in a single building form.

Source: Schematic map of the Millennium Point provided by Grimshaw Architects, edited by researcher

Fig. 7.3.1-3. Millennium Point, Birmingham designed by Nicholas Grimshaw & Partners

Source: Photographed by the author, 2014

According to the planning application, the total floor space is 37,207 sq.m, and it have five main floor levels. The major section of the building which containing the THINKTANK and the TIC has a principal elevation facing Curzon Street, but set back approximately 65m from the street, which left as a generous, urban public space and monumental axis flanked by green zones and water features (**Figure7.3.1-3**). The THINKTANK occupies the west part of the building occupies the western part of the linear element, which linking it firmly into the industrial history of Digbeth[20]**.** This end of the building acts as a draw for pedestrians arriving along Albert Street from the city centre, the part of the building containing the Hub and IMAX cinema in front, extending towards Jennens Road, also includes a principal pedestrian access to the development. As mentioned, these two pedestrian entrances align along a strong north-south pedestrian axis forming a through route which is a major design feature of the development (**Figure. 7.3.1-2**). Changes in level across the site is well-designed and accommodating within the architecture along this route - when visitors arrive the Hub from different directions at various levels, they can easily approach THINKTANK and TIC via those escalators and elevators in the lobby area.

The external elevational design varies between different parts of the building. The principal (south facing) elevation of THINKTANK and TIC facing Curzon Street have an entirely glazed curtain wall system, giving view of activity inside the building at all level. But THINKTANK is distinguished from the Technology Innovation Centre by an external loured screen in front of the glazing constructed of terracotta slats (**Figure7.3.1-4**). The 'front' northern facades is seen as being open. The screen begins at first level, as the ground level is glazed to provide pedestrians clear views of exhibits and machines inside THINKTANK. The elevation of the TIC is totally unscreened as there is a requirement for full natural lighting. This part of the elevation would incorporate the "solar chimney", which can be used to improve natural ventilation in buildings by encouraging the convection of air upwards. Ground level glazing would extend around the north, east and west elevations of THINKTANK and TIC, and above ground level, these elevations is cladded in a system of interchangeable zinc panel, some with small windows. As shown in **Figure7.3.1-4,** The

[20] Digbeth is an area of Central Birmingham, England. The area around Digbeth was the first centre of industry in Birmingham and became one of the most heavily industrialised areas in the town.

IMAX cinema and Hub sections of the building have a less regular, more articulated elevation contrasting with the very geometric, formal character of the south elevation.

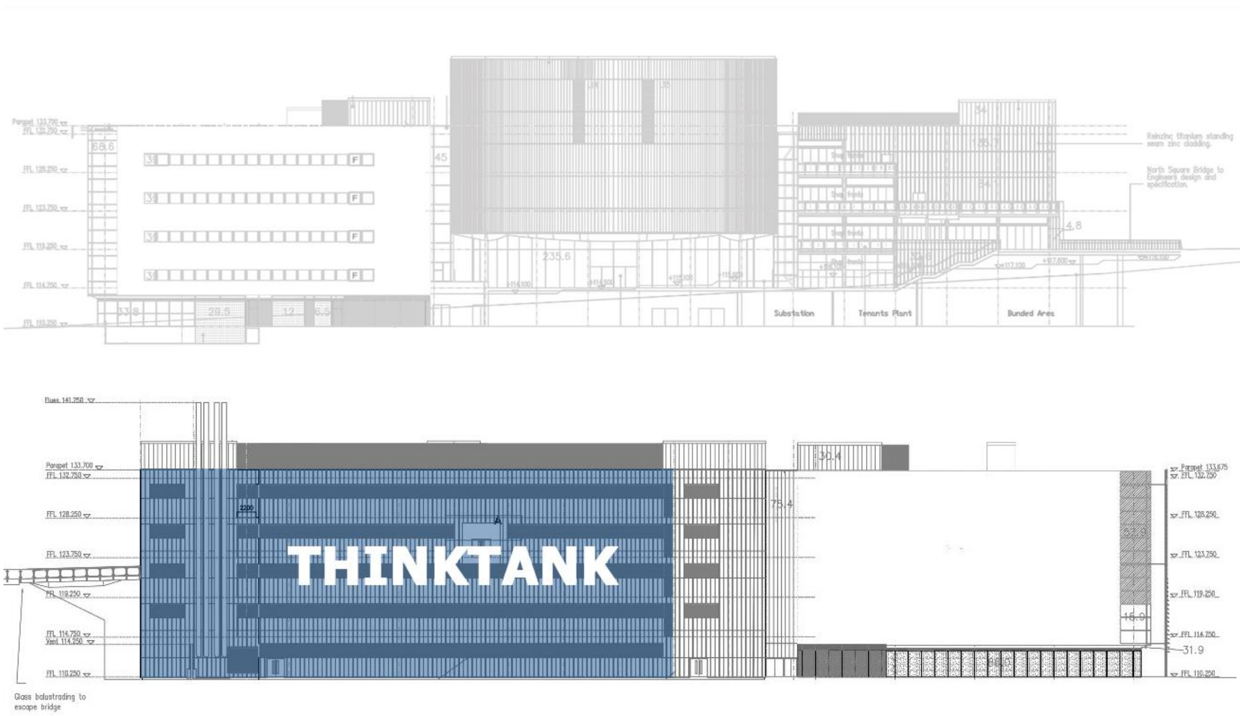


Fig. 7.3.1-4. The "front" north elevation and the "back" south elevation of the Millennium Point.

Source: Elevation drawings provided by Grimshaw Architects.

The building is finished and opened on time and within budget on 29 September 2001, then was officially opened by Her Majesty the Queen on 2 July 2002 ("Our History, Millennium Point", N.D.). The extent to which science centres can contribute to regeneration and the local environment is well illustrated by this project in Birmingham - in the context of the city's economic and social regeneration, the presence of THINKTANK as a family visitor destination has contributed profoundly to the changing perception of Eastside, as part of the City of Birmingham (Ecsite-uk, N.D.).

7.3.2 Guiding concept and project development

THINKTANK wants to promote public understanding of science, technology and history. It includes the refurbished science and industry collections and covered old favourites brought from the former

Birmingham Museum of Science and Industry – such as world's oldest working steam engine and spitfire aeroplane used by the Royal Air Force. However, the museum also adopted new ways of interpretation and augmented technologies. It was set to create 21 century museum experience and immersive scientific exhibitions for general public, and facilitate as a focus point for varies of activities, which aimed at providing a catalyst for the continued regeneration of Birmingham. In addition to that, Birmingham City Council Education Services also have an Education Development Plan and similar priorities with schemes to support schools such as Excellence in Cities and Discovery Centre will support and become an important partner in the delivery of these objectives and schemes.

In summary, the educational objectives and design intents of the THINKTANK are:

- To bring a fresh perspective of awe and wonder to the study of science, technology and history through the collections and demonstrations of live science and technology.
- To promote the enjoyment and fun of learning by offering a stimulating and challenging learning environment with a variety of activities, interactive exhibits and live demonstrations.
- To allow all visitors the opportunity to engage with real objects and interactive displays and to develop ways of investigating and questioning science, technology and history for themselves
- To provide access to cutting edge developments in science, technology and industry, and to make this expertise available to visitors of all ages through the collections and programmes.
- To enhance all visitors understanding of the world around them and their past through the collections displays and additional education programmes.

As mentioned, the purpose of developing the THINKTANK was to explore aspects of the technology, industry and science, social history and natural history collections to provide an excellent museum environment (Met Studio, 1998). The outcome of project planning set out the strategy for proceeding with the museum schemes as: to create, through the provision of an innovative world-class visitor attraction, a unique meeting place for people to discover, enjoy and share the remarkable contribution of Birmingham and its region to the wider scientific, industrial and technological processes which shape the modern and future world.

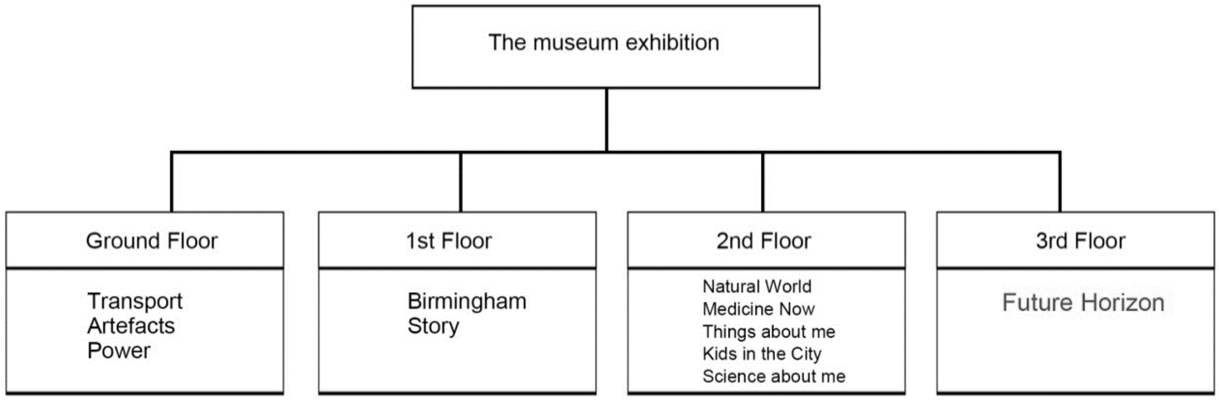


Fig. 7.3.2-1. Exhibition Content at the Thinktank

Source: Adapted from Met Studio, 1998

There was a total of eleven exhibitions in technology, general science, industrial era and space exploration in this science museum, as the diagram (**Figure 7.3.2-1**) indicates a clear timeline from the ground floor to the 3nd floor based upon different historical themes, such as exhibitions presenting scientific inventions of the past, demonstrating the impact science and technology has made on the world of today and emerging technologies expected in the near future.

The Future Horizon exhibition is the latest renovation project inside the THINKTANK, providing a world-class exhibit experience that teaches STEM-based content via a fusion of augmented technologies and sensory system. The focus of the exhibition is on the concepts common to all space flight and so uses the narrative of a possible future space mission, as opposed to any particular historic mission, as the framework to communicate these ideas. The medium of the interactive game, as exemplified here by the spatial interactions and simulations that make up the core of this Future Horizon exhibition, speaks powerfully to children as adults. It is well-known that interactive games are so compelling is precisely because they are fun way to learn, in this Future Horizon exhibition, museum learning is real and integral to the play inside those augmented spaces. And the design of those interactions balances the possibility of failing with the reward of achievement and the satisfaction of success.

The design intent of the Future Horizon exhibition is allowing all visitors to learn about the challenges and excitement of space travel, then apply that knowledge as they 'fly' the spaceship, pilot the landers, and drive the rover, in a thrilling narrative adventure to Earth orbit, the Moon, and Mars.

Project development process

From the tender document provided by Met Studio, the whole science museum project was divided into 4 main sections: Content, Design, Contract, and Technical design (Met Studio, 1998). The aims and purposes of the project were set out in a preliminary stage. Eleven exhibitions were identified in advance to establish museum plans and provides the overall themes of museum. The most significant aspect of project development was the adoption of a principal design process model in order to carry out the design tasks set by the client. Design information management was therefore an essential factor in coordinating and communicating across different disciplines. Because of the client - the Birmingham Museums Trust did not have the capability to manage such a big project with eleven exhibitions in 900 square metres, Fraser Randall Production Ltd. (FRPL) was appointed by the Trust as the design consultancy and manage this project. The company was in charge of conducting and managing the overall exhibition project from the beginning of project planning to the end of production work. Subsequently, they hired exhibition design groups to conduct for detailed exhibition development for each museum theme, and they also invited specialist subcontractors, such as interactive experts, digital technologists, scientists, educators and computer experts to participate in this significant exhibition project.

At the early stage of the project, FRPL provided the overall design brief, the outline contract, the overall concept proposal and educational objectives. All the contractors, including those museum specialists, interactive experts, architects and designers followed this brief and wrote the terms and scope of their work based on their professional expertise. All of the participants attended progress review meetings to discuss details. The museum specialists and curators provided ideas and relevant information for designers to develop the design concepts. Many decisions were brought to the general development meetings for approval by the client. This was an important meeting function that reviewed design progress, as well advising designers of changes or to proceed to the next stage based upon the client's requirements.

HKD studio was one of its subcontractor for the Future Horizon exhibition, it's is a small design firm which focuses on developing museum exhibition projects in Margate, UK. The company has about 20 employees which includes 9 museum designers, who had to attend every weekly review, creative direction and general development meetings to present progress reports as well as discuss the content and planning. In order to assist the designer to develop the concept, a number of specialists were also appointed to provide subject information and assist HKD for the exhibition design process. According to the tendering specification in the Contract, HKD was responsible for implementing the project from generating the design concept to handing over the design results for conversion into production work. The design concept was discussed at group meetings, after all members of the development team agreed with the concept, a design specification was provided to illustrate exhibition features. The exhibit features included: the educational message, activities, description, components, picture / film requirements, audio requirements, augmented technology details, graphics, illustrations, user interface and estimated cost.

Stage 1	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**
Appraisal and Design Brief **Equivalent to RIBA Stage 1**	**Concept Design** Equivalent to RIBA Stage 2	**Design Development** Equivalent to RIBA Stage 3	**Construction Specifications** Equivalent to RIBA Stage 4-5	**Production, Installation and Completion** Equivalent to RIBA Stage 6
Start Up Feasibility Survey Interpretative Planning Sketch Ideas	Concept Design Outline Script Being Research Cost Estimates	Design Development Draft Script Educational Research Review Schedule	Finalise Design Full Script Identify all Research Sources Project Management	Review and Approve Final Design and Script Project Completion Procedures

Fig. 7.3.2-2. Design stages for Future Horizon Exhibition from HKD Studio

Source: HKD studio, 2004

To maintain the educational integrity of the exhibition, this exhibition design project has been developed with the collaboration of a distinguished advisory panel, which includes the UK's leading scientists, widely recognised for her outstanding contributions to research and to public engagement. The design process took great care to examine just what it is that visitors are learning and to try, and make the desired educational materials an integral part of the design. The education in the Future Horizon exhibition is baked into the core of the experience and attempts to give visitors an instinctual understanding and relationship with its subject matter – the principles of physics and motion that govern all of spaceflight used in universe exploration. The renovation project of the Futures Gallery was lasted for 10 months. The new interactive scientific exhibition transformed the original gallery space with embedded digital technologies, stimulated a new immersive museum environment.

7.3.3 Physical setting and exhibition narrative

This exhibition gallery is located on the top floor of the THINKTANK. In general, fundamental to the interpretive approach of the exhibition gallery is the fact that it was not only targeted at children. The exhibition purposes are to create and develop a widespread appreciation and understanding of space science and the aerospace industry. It is a key feature of the THINKTANK that its exhibitions are relevant to scientific criteria. A special emphasis was placed on the planning methods, styles as well as the functions of the gallery so as to improve the public understanding of the space science. The project also required a suite of interactive exhibitions to inspire, engage and inform visitors; consequently, many AR augmented spaces has been planned inside the gallery.

According to the typology of experience realms based on the nature of experience factors and how they work and interact by created Pine and Gilmore (1999). The experience inside Futures Gallery are both 'Active' and 'Immersive' – 'Active participation' refers to the situation where visitors engaging inside THINKTANK is directly influencing the whole scientific exhibition performance; 'Immersion' refers to the activity they performance becoming part of this exhibition experience. However, unlike Air Pavilion which with single exhibition theme and the exhibition setting inside relatively compact with clearly bounded shape, there's no clear boundary of the exhibition area for the Future Horizon exhibition, as it contains different scientific topics, and different exhibition displays were visually and spatially coordinated according to these topics. The author has defined five themes according to the exhibition plan of Futures Gallery (**Figure 7.3.3-1 and Table 7.3.3-2**), following Info Grove, Technology Showcase, Space Travel (Interactive table

'Virtual Space Flight' and Interactive AV presentation of Space Travel), Search for Alien (Space Suit Exhibit 'Be an Astronaut' and Interactive monitor AV presentation of 'Search for Alien') and Missions to Mars (Explore Mars and Mars Rover Display). Visitors learn about the challenges are the excitement of spaceflight in this exhibition, then apply that knowledge as they fly the spaceship, pilot the landers and drive the rover, in a thrilling narrative adventure to Earth orbit, the Moon and Mars. Those advantage technologies also help to support collaborative learning and co-construction of knowledge.

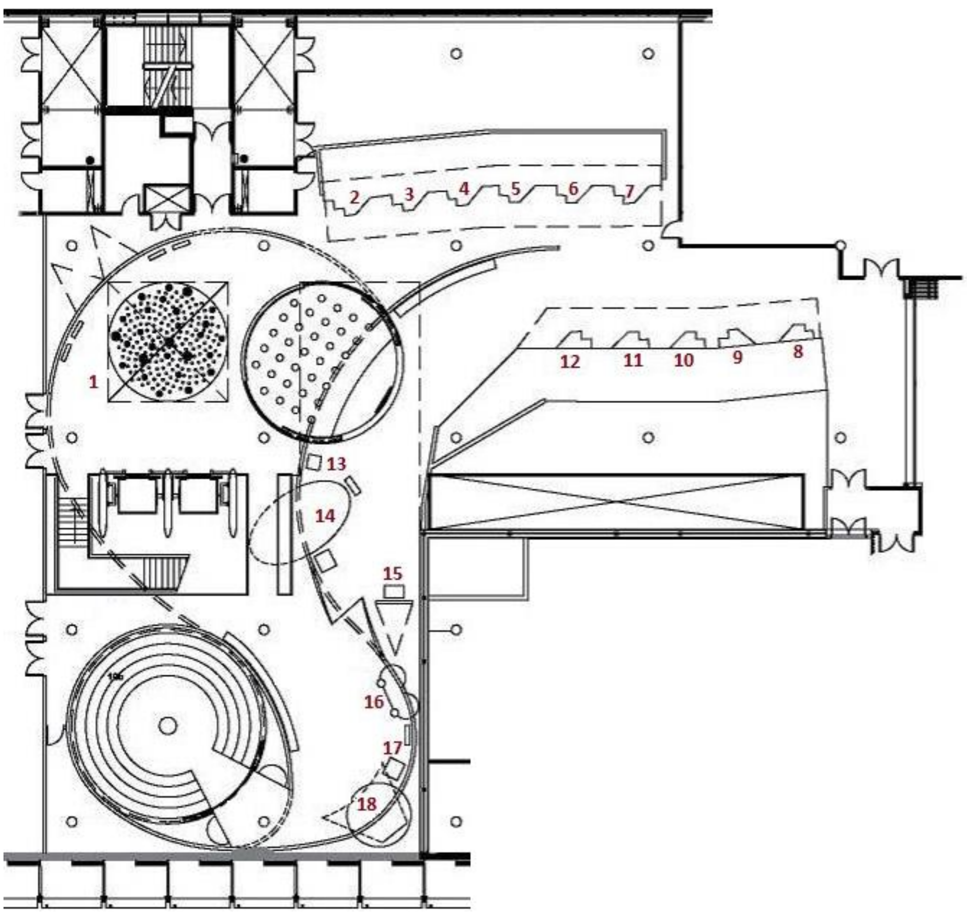


Fig. 7.3.3-1 Exhibition floor plan of the Futures Gallery

Source: HKD Studio, edited by author

No.	Exhibit Title	Exploring instruction	Technologies
1	Info Grove	Find out the latest science news and technological artefact	Interactive monitor

2-12	Existing Showcase Exhibition	Interact with world-changing innovation, including: super-bodies, robotics, sensors, micro-machines…	Interactive monitor Physically hands-on
13	Virtual Space Flight	Land the space ship on the moon	Interactive table
14	Space Travel	Take a tour round Into Space and you will come face to face with astronauts, and the journey into space.	Interactive AV presentation
15	Be an Astronaut-Space Suits	Look at the displayed training space suit	Static object-based exhibit
16	Search for Alien	Take a journey to find out… Are we alone? Is it possible to find life beyond earth?	Interactive monitor AV presentation
17	Mission to Mars	Explore mars via curiosity's journey, free dive, learn about the rover, gale crater spirit's journey and mars globe	Interactive wall
18	Mars Rover Display	Send instructions to the Rover to make a journey to take a photograph of a surface feature on Mars	Interactive exhibition

Table 7.3.3-2 Exhibit list of the Futures Gallery

When visitors step out of the staircase and enter the exhibition gallery, *Info Grove* is the first exhibit zone that visitors will be confronted with, it contains 2 of 200mm internal lit coloured acrylic tubes and 4 of 400mm internally lit coloured acrylic showcases, with several great latest innovations exhibited inside, which composed the orientation area with a massive introduction mural on the partition wall as surroundings. Following that, visitors will then step into the existing showcase exhibition, in this area, great innovations that have shaped our world are presented one by one along the corridor, which includes super-bodies and bionic technology, Robotics, Sensors, New Material, Emotional Machines, Micro-machine, Nanotechnology, Micro Air Vehicle (MAVs) and Robot Arm. This showcase exhibition doesn't belong to HKD's Future Horizon exhibition project, but with interactive monitor and physically hand-on artefacts, this existing exhibition makes a perfect connection between the orientation area and the furbished exhibition space. There’s also a life size, interactive, fully programmable humanoid robot exhibit called RoboThespian™, which is powered by compressed air and moving on a specially developed scene. The multilingual, user-friendly interface and eye-catching appearance make this robot a perfect device to communicate with the museum audiences.

Fig. 7.3.3-1. Exhibition Content inside Future Horizon Exhibition *Top left:* the entrance of future of space zone; *Top middle:* the static object-based exhibit - Space Suits; *Top right:* Top view of the ‘Info Grove’ *Bottom left:* Virtual Space Flight Station; *Bottom middle:* Space Travel and Be an Astronaut; *Bottom right:* Mars Rover Display

Source: Photographed by the author, 2015

Returning to the right end of the existing showcase exhibition, the route reaches the *Space Travel* exhibition zone, including a virtual space flight exhibit which simulates the moon landing experience adjacent to an interactive presentation of the "Journey to Space", the companion to the large-format movie of the same name, which explores the history and bright future of human space travel, along with the risks and innovative solutions involved. “It will present the virtual space flight exhibition and interactive AV presentation together is giving guests a deeper understanding of the space exploration challenges facing the next generation." said Richard Houghton, the chief curator of the exhibition. With the massive back mural on the partition wall with few spotlights to highlight stairs in distance as the background, mysterious atmosphere is created for encouraging visitors to explore the journey of space. Through interactive games and multimedia components, visitors will find out how astronauts work in the space station. With two exhibits ‘Be the Astronaut’ and ‘Search for Aline’, two multi-part video games will illustrate how astronauts are trained for missions into deep space to find possible life beyond earth. The last part of the future horizon exhibition is looking at the Missions to Mars, this is also the last zone visitors interact with before they enter the Planetarium for full-dome space show. The narrow space is enhanced by bringing augmented technologies, which also support visitors’ experiences of moving through the physical space.

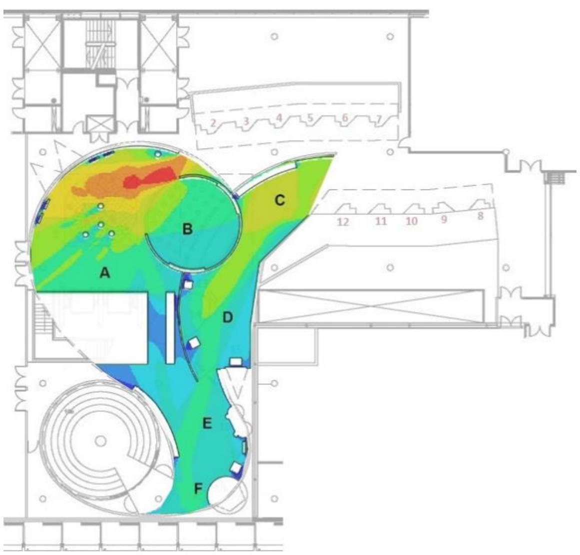


Fig. 7.3.3-2 Visibility (Left) and Permeability (Right) through VGA analysis.

The author also adopted space syntax analysis for this exhibition space, as shown above (**Figure 7.3.3-2**). Through the VGA analysis, the visual connectivity graph (left) is generated at the eye-level, which includes the all visually accessible areas in the analysis. It demonstrates that the regions with the highest degree of visual connectivity are at the region between A and B, which are right above the exhibit - *Info*

Grove. This demonstrates the visitors have great visual access to this introductory exhibition space. The second tier of the high visibility area is located on Zone C. This is a transit area between existing Showcase Exhibition and the case study Future Horizon Exhibition, there's not a single exhibit has been located on this space, visitors would normally just walk past this zone with only a few choose to have a short break on the bench against the curved wall.

The knee level of the VGA map, indicates that at the permeable level of the gallery (on the right picture), the high connectivity value is distributed at the same area which enjoys high rated visibility. The highest value of permeability is also situated within zone A and zone C, the left side of zone F also indicates a high level of permeability through the gallery. That is because it is closed to the entrance of the Planetarium, which offers extensive vistas to all the surrounding spaces inside the gallery so it is highly integrated.

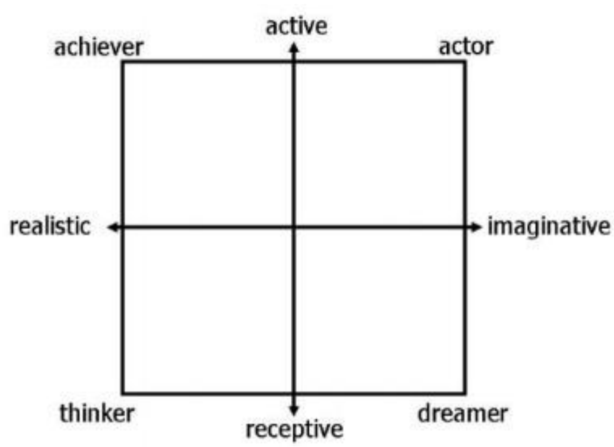
These analyses indicate in those exhibition areas like zone A and zone C, museum visitors are exposed to an unobstructed overview of the gallery's core bringing to the foreground visitors' experience, and a continuously open interior might be programmatically subject to attractiveness. In the meanwhile, through our observational study, it seems the visitors on these areas are impossible to concentrate their attention on a single exhibit for a long period of time. On the contrast, exhibition area like zone D, E and F, which with a low level of visibility and permeability are, in fact, where the in-depth interaction and the majority if informal learning is produced, they have longer holding power, and higher visitor engagement levels.

7.4 Analytical Studies

7.4.1 Different visitor groups inside museums

In a social group, each member has a certain role and is next to being a part of the group also an individual having specific opinions, demands and wishes. This is even more pronounced in a museum environment. The interaction between adults and their children is crucial for an experience together but the trigger to get one's attention or interest differs to a large extent. To be able to consider the demands for both target groups equally for the museum settings, the preference and perceived experience for children and adults are first analysed and discussed separately and then regarded in the family interaction inside these two scientific exhibition settings.

Children - From day one after a child is born, the development and communication with its surroundings begins. Each day new experiences form the character of a unique individual. Some children start speaking before their first birthday and others are able to walk before they pronounce a word. But even though it always has to be considered that no child is like another it is possible to generalise certain characteristics. Mathieu Gielen once introduces two dimensions to determine a child's behaviour and personality which are "realistic versus imaginative and active versus receptive" (Gielen, 2010). He provided a diagram which is loosely based on the diagram of learning styles developed by Kolb (1984), two axis of the diagram shows different types of a child can be derived, as shown in **Figure 7.4.1-1.**



- **realistic + active = "achiever"**
- **imaginative + active = "actor"**
- **realistic + receptive = "thinker"**
- **receptive+ imaginative = "dreamer"**

Fig. 7.4.1-1 Diagram of behaviour types.

Source: Developed by Kolb (1984)

As Mathieu Gielen claimed, the four corners of the above diagram represent four opposite behaviour styles, for example, when children more into imaginative motor behaviours, or they tend to 'acts out' a story, it makes them "actors". Receptive realistic behaviour leads to a 'thinker' play style in which experiencing and discovering the characteristics of the surrounding world will be the focus (Gielen, 2010). When the author conducted the field observation inside both the MAGNA and the THINKTANK, these four types of child behaviour can be identified and illustrated as the figure below (**Figure 7.4.1-2**).

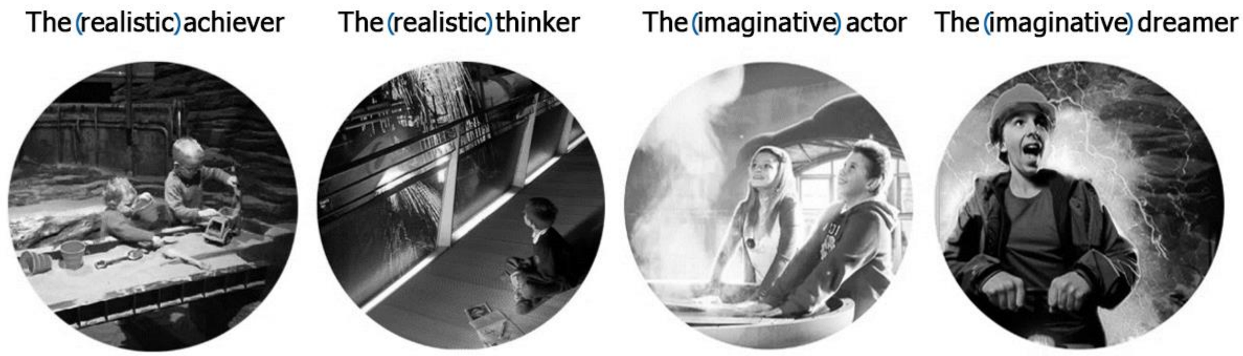


Fig. 7.4.1-2 Illustration of the four child behaviour types, identified inside two museums.

Source: Photographed and edited by author, based on Kolb (1984) & Gielen (2010)

While the dimension of realistic versus imaginative focuses more on how children think and process information in their own mind the level of active versus receptive is based on how certain types of children absorb and thus understand information which can be summarised as a child which learns better by doing something and a child which learns better by thinking. Both types of children and the differences in interaction with the exhibits were also observed, as the 'thinker' was recognised as the quieter one who observes before starting to interact with an installation, while the 'doer' often is more active and rather starts to interact than considering first how something could work or what the meaning of an interaction is.

Next to the personality of a child also the age has an important impact on the behaviour. Sharman et al. summarised the development in four main categories: "The physical, the intellectual, the social and the emotional development" (Sharman, Cross & Vennis, 2004). Each of these categories plays a role in how children interact with their surroundings. For example, Sharman et al. state that a three to five years old children still "needs support and reassurance" whereas a six to eight years old already "moves away from adult dependence".

This theory is enforced in the field observation in these two museums, as one visitor claimed that "Many things were too complex for our four-year-old son, but the older one (about eight) didn't need any help, in that case, my husband and I just split up for the visit, so he could go through the exhibition with the older one and I took care of the younger." Based on the findings, it can be said that with the ageing of a child the recognition of objects increases as well as the ability to understand more complex topics because of a shift from being self-centred towards a focus on others and the world around. **Figure 7.4.1-3** visualises this theory from a three-year-old to a twelve-year-old.

	3-5 years old	6-8 years old	9-12 years old
dependency on caregivers	still needs support	need support in difficult situations	is able to interact independently
contextual understanding	focuses on the direct surroundings	focues on experienced situation	starts to understand the complexity of situations
classification of objects and situations	can recognise and name objects	ability to recognise situations on images	can interpret and reflect fictional situations

Fig. 7.4.1-3 Table of the child development from three to twelve years old, based on findings pf sharman et al.

Source: Author, based on Sharman, Cross and Vennis, 1995 Acuff and Reiher, 1997

Additional to the above-mentioned certain behavioural details, specifically relevant for planning an exhibition, were observed in the MAGNA and THINKTANK. For instance, the ability to concentrate on a certain topic and the attention span are a major issue. Especially when children have to read a lot, there is a tendency that they lose interest very fast. The author observed a group of children (13/ 14 years old) who are trying to play Good Vibrations[21] inside the Air Pavilion. For understanding the purpose of this game reading is required but instead of doing that the group played around for a short while and then they quickly moved on to the next installation. Besides that, since the focus of the MAGNA is rather on older

[21] Good Vibrations is an interactive exhibit which explore sound waves and resonance inside the Air Pavilion, MAGNA.

children, also the exhibition and the installations are designed for such a target group which results in younger children being over challenged. This is backed up by visitor comments like "My 5-year-old boy found it a bit too advanced though" and "It is important that a child can read to get the most out of the permanent displays." One of the arising problems is that it does not only affect the child but the entire family, because when children are not able to interact with the exhibition by themselves, they need the help of an adult.

This situation also points to the next factor that social interaction defines the experience in the exhibition. Depending on the social group in which children are visiting the museum the way they act differs. When being with friends, the opinion of the other person is rather important if an object or an installation is interesting or 'cool' enough; whereas when being with parents, both parties inspire each other to look at specific objects; and when being in a situation of a workshop the adult's approval and the own success becomes more important.

To address as many children as possible in the exhibition, especially the active and passive behaviour is something to keep in mind. Interactive installations and its surrounding augmented space should offer possibilities for both, a child which processes while thinking, as well as a child which actively wants to do something. For hands-on interactive exhibits, a balance between challenge and ability for each age group is essential to offer a feeling of success to different levels of knowledge and capability. Not every installation has to be focused on all age groups but offering a range of installations for different target groups will help to include also the young ones in the museum experience. Furthermore, it can be considered to include more social interaction in the exhibition like collaboration or competition which will benefit the children. Besides the behavioural characteristics, the preferences of children can partly be integrated. Moreover, the author believe written information should always be supported by pictures and the context to first trigger the interest of a children about a subject which then makes they want to know more.

Adults

Although both museums target on children, the author still got some impressive feedbacks from the adult group. E. W. Taylor (2010), an adult education theorist, once defines adults' visiting in museums as "the incidental unplanned and unconscious learning that is most prevalent as visitors wander around" (Taylor, 2010). He referred to the visiting pattern as unplanned, incidental, and unconscious in terms of no guide or set tour. Adult visitors usually approach and engage with exhibits on their own, and they hardly rely on others to explain, but interprets the meaning for self. In addition to that, while the author was researching positive museum experiences of adults, it becomes clear that their preferences are highly dependent on their personal interests. Adults also tend to focus their attention on background details an exhibit, a large number of adults mentioned MAGNA impressed them with the vast spatial structure with the proud history of the steelworks. For them, the more immersive an object is exhibited and put into the context of its use, culture or situation the more likely it is that people are able to remember it. During one of those semi-interviews with an adult visitor, he mentioned the most impressive part of his MAGNA experience was the "big melt" - this exhibit using lights, sound and special effects to bring giant blast furnace back to life, besides that, all historical memories were exhibited in context with the people who worked there, dimmed light and narrow passages.

Another point which enraptures people is when they can connect their own prior experiences with subjects or objects in the exhibition, as Monk once claimed that the connection between the exhibited content and one's life enables adults to understand and reflect on their actions and certain prejudgements and that this is the key for adult learning (Monk, 2013). Being able to imagine the context and the life around a historical object lets adult feel connected and lets them create a more tangible story. Small facts which cannot be looked up online make the museum visit even more special and help to remember what one has seen. It seems that the closer the exhibition comes to an experience which people can imagine, the more it will create an understanding of the past cultures and current technologies. Based on extensive research on adult learning in museums, through the field observation in both museum settings, the author found adult visitors are willing to spend a fair amount of time reading the labels and discussing the science behind the exhibits, they are also eager to learn new scientific knowledge inside museum environment.

Families

From the previous literature reviews, the author found that social interaction is an interesting form of learning, based on being entertained as a family and having a social experience. Within the family learning, several types can be distinguished, and there are different learning styles. Families learn in another way than other visitor groups, therefore this group needs special attention in the development of exhibitions and products. Family learning in museums is often adult-led but child-oriented. Adults must feel able to make use of the available resources to guide and stimulate the interest of their children. Intergenerational learning is an interesting form of learning that relates to families. This learning form should therefore, together with social interaction, be taken into account in the development of the explorative family expedition.

Haden once investigated the impact of family interaction during such hands-on interactions in a museum environment, they discovered that the communication between children and their parents increases the quality of the experience and the chance of people memorising facts and content of the interaction. They also noticed that subtle instructions to ask each other questions can increase the communication (Haden et al., 2013).

In the course of family observations in the MAGNA and the THINKTANK, it was recognised that most families stay close together during their visit. The majority of adults take great care of their children and communicates with them during the experience. But in some interactive galleries like the Air Pavilion and the Futures Gallery, they create a playground atmosphere where children are running around and trying out everything while adults are waiting for them in the distance. Moreover, current exhibition exciting installations for children and interesting information for adults are mostly separated (**Figure 7.4.1-4**). It is up to the parents how much they communicate with their children. From the observation, the author believes that offering installations which allow both, adults and children, to interact with each other and explore for themselves, is a chance to trigger additional and valuable conversations between family members. It is important that each family member is challenged individually during the visit to avoid the impassive behaviour.

Fig. 7.4.1-4: As shown in figures above, during the visit some interesting parent behaviour was observed that can be split up into two types: involved and not involved with their children. Most parents at any given moment were demonstrating any of the following behaviours, in no particular order.

Source: Top left: Solving or working together inside the water pavilion, the MAGNA; Top right: Adults' participation only inside the Futures Gallery, the THINKTANK; bottom: Solving or working together the Futures Gallery, the THINKTANK. Photographed and edited by author

Beside the disconnection between adults and children in current exhibition setting, the author also noticed some installations are designed for older children which results in younger children being over challenged, which does not only affect the child but the entire family, since those younger children are not able to interact with the exhibition by themselves and need help of an adult. During the field research on site, it was frequently observed that this results in parents rather helping their children to interact than getting involved in the subject. But it gets especially challenging when one adult is accompanied by one younger child and one older child. In that case, the grown-up needs to take care of the younger one while the older one has to be autonomous. In this specific example, when interacting with Turbulent Orb[22] inside the Air Pavilion, the mother read out the questions and the older sister immediately reacted and jumped on the right answer but for the younger brother, the questions were too difficult and he needed all the attention and support of his mother. While the sister was then impatiently waiting, the brother got frustrated because of not being able to catch up with his sibling (**Figure 7.4.1-5**). Some families also mentioned they want to discuss the objects together as a group, they like to answer questions and discuss the things they see. The children always have a major role in these discussions and the complete museum visit, then the adults adjust the visit to the motivation and energy level of the children.

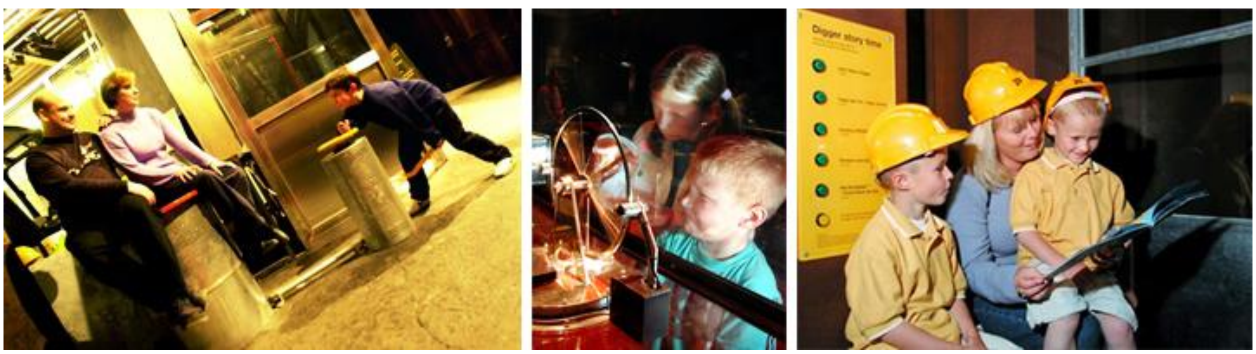


Fig. 7.4.1-5: Left: Inside the MAGNA, A boy tried to spin up his parents' chair; Middle: An older sister waiting for her younger brother to be done with playing with the hands-on exhibits; Right: A mom was reading instruction to the younger boy in side JCR digger, the earth pavilion.

Source: Photographed and edited by author

7.4.2 Configuring museum experience model

Followed by those visitor analyses from the field observation, the author summarised different museum experiences perceived by different group of visitors (which includes children, adults and families). Based on the review from **Chapter 5,** the museum environment can be best described as a mixture of personal, physical and socio-cultural contexts (Falk and Dierking, 2000; Falk, 2009). The subject of this subsection

[22] Turbulent Orb is an interactive exhibit inside the Air Pavilion, it shows chaotic fluid patterns swirl in unpredictable ways, representing how Earth's oceans and atmosphere.

is to divide museum experience of those two museum cases over these three contexts. Through the field observation, some museum visitors prefer to explore the museum alone, looking at the social context of the visit. He /she does this because he doesn't like to be disturbed in his/her quest for interesting objects and information. Other visitors do like to share his experience by discussing and talking with friends and family. **Figure 7.4.2-1** summarises interactivity for museum visitors. When looking at the personal context of the visitors, it is important for them to expand their knowledge and learn by doing. Using an interactive exhibit with constructivist learning approach can help them to understand and remember things, which is less likely to happen by observation and pure studying of objects. Also, they are normally curious and want to experience something totally different, and new interactive experiences in both galleries have been successful in taking their visitors into an unknown and mysterious world which they can keep exploring.

In the physical context of the interactive, the real thing is central, just like in the museum experience. Museum visitors are interested in interactives about objects, phenomena or stories related to the subject of the museum. This information has to be made relevant for them and take into account their knowledge and interests. Also, both children and adults want to be able to influence the interaction to discover the things that they are particularly curious about. It is crucial to personally experience what the interactive has to offer and not being a passive bystander. While using the interactive, museum visitors do like to discuss which actions are best to take and to be helped in the interaction, in which way he/she learns best.

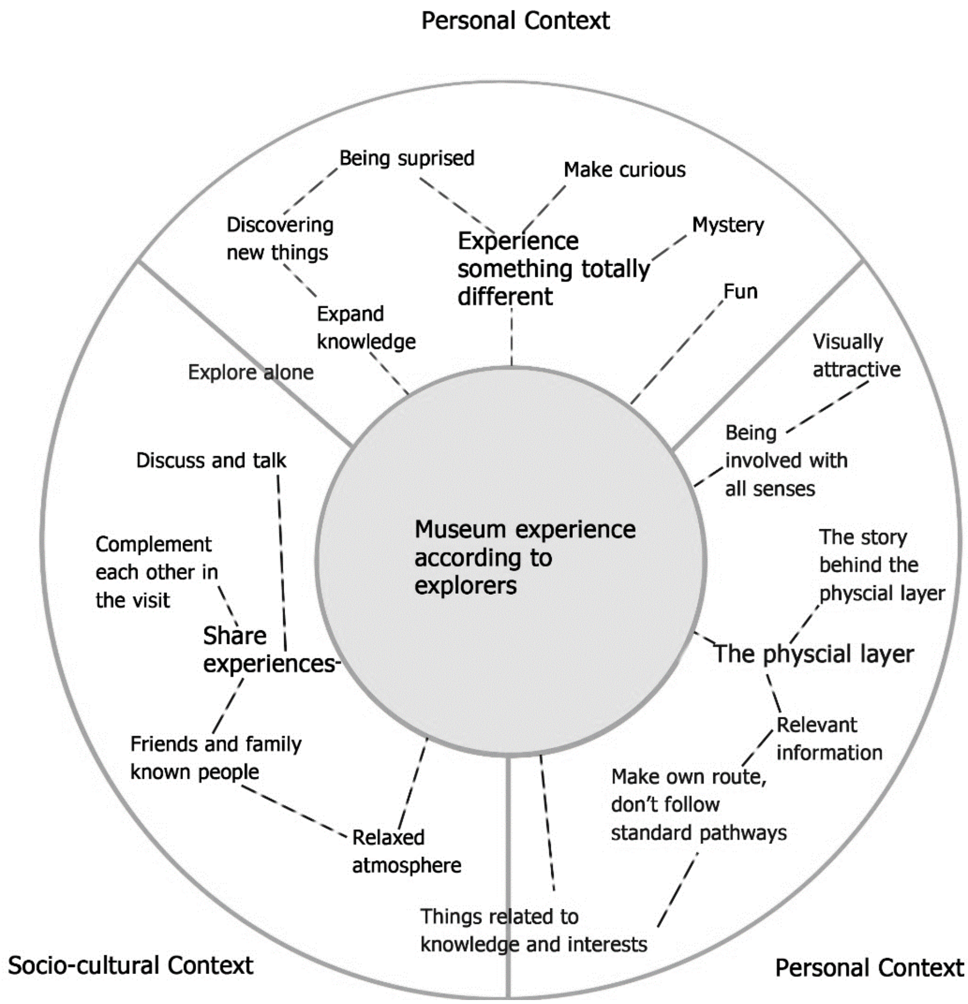


Fig 7.4.2-1: Museum experience perceived by museum visitors detailed for the three contexts

The physical context:

People's experience of the exhibition was very strongly associated with its aesthetic and material qualities. Two cases like MAGNA and THINKTANK both appear to have had a particular impact on people: its pleasantness, the presence of interesting props and ornaments, the presence of areas for sitting down, the lighting and general "feel" of the place were noted and appreciated by virtually all the visitors. These elements of the physical dimension are connected to the individual and cultural ones, as we will see in the following sections. This finding suggests to designers how important the physical dimension is when developing an augmented space: not only AR technologies should be seamlessly embedded within the environment, but also the entire space should be carefully designed to ensure continuity of materials, comfort and attractiveness. Another positive feature of the physical setting of a scientific exhibition is the fact that it supported the presence and interaction of children as well as adults, groups as well as individual, family group needs to pay extra attention to make sure there's interaction in between. This connects the physical to the social dimension as well.

The personal context:

The personal dimension of the experience of the exhibition emerged most clearly in the examples of people's reflections of the feature augmented space in the gallery. People engaged in the activity and, through interactions with the technological components, their investigation was supported and encouraged. But people also put their personal knowledge, memories and feelings into it. This aspect of the experience is strictly connected with the social dimension, as this became often a topic of conversation and debate with others. As we noted in the previous section, visitors reacted very strongly to the material qualities of the space as well. As well as the interactions with the technology, the exploration of both galleries (Air Pavilion and Future Gallery) was an integral part of the experience of the exhibition for adults and children alike.

The socio-cultural context:

As the author has noted in **Chapter 5.3**, the capability of the augmented space to support individual and well as group interaction is the most immediate elements to shape the social dimension of the experience. It was possible for small and larger groups to collaboratively experience the augmented space. This also triggered discussions and debates over the objects that sometimes continued even after the visit. Another element that greatly affected the social dimension of the experience is the presence of other people's traces. The author has shown earlier how the opinions worked not only as a trace of one's presence, but also as resources for exploration and discussions as well as triggers for casual social interaction.

The cultural dimension of the experience was affected by two main elements: the fact that the exhibition allowed different rules of behaviour than those commonly in place in museums, and the strong links that these two museums presented with their culture and identity. Regarding the first element, the physical design of the augmented space aimed at immediately communicating to visitors that they were now entering a 'special' place within the museum, thus they would be allowed to touch, get closer and fully immersed inside the museum environment. Regarding the second element, the link with MAGNA and THINKTANK were presented in both the overall activities.

7.4.3 Analysis of featured augmented spaces

Air Tornado Experience

A tornado in the nature world is a violently rotating column of air which descends from a thunderstorm to the ground, according to Michael McCarthy. No other weather phenomenon can match the fury and destructive power of tornadoes, it can be strong enough to destroy large architectures, leaving only the bare concrete foundation (McCarthy, 2013). At the same time, tornadoes range in size from tens of metres to one kilometre in diameter, so intense damage is normally restricted to a small area. The Air Tornado Experience is the feature augmented space inside the Air Pavilion, Magna Science Centre, which created a chance for face to face interaction with one of the most terrifying and spectacular phenomena in nature.

This fiery display is standing 40 feet tall inside the Air Pavilion (Zone I), Magna Science Adventure Centre, it looks like a spinning tornado which swirls from the floor all the way up to the ceiling of this hanging pavilion, changing shape and moving around – controlled by the museum visitors. The air is created by 48 ultrasonic misting foggers and four giant fans in the ceiling of the architecture that creates a swirling air flow and draws the fog up from the ground, an exhaust at the top of the exhibit draws air and water vapour upward. The result is a beautiful, lively, gentle tornado which reacts to a visitor's touch, as shown in **Figure 7.4.2-1**. Vents on the side open and close base on controls operated by visitors and change the tornado's shape and form. At the same time the embedding coloured LED lights will light up the tornado from below, with the LED instruction panel, this illustrated water vapour tornado is also changeable with visitors' choices. The lighting feature of this augmented space is very appealing to the family with younger children.

The purpose of this exhibit is to teach museum visitors about a natural phenomenon. At a basic level, a tornado is formed by horizontal shearing winds combined with an updraft. And the wind shear created by the offset orientation of the inflows. This exhibit is also intended to allow the visitors to see the how the shape of a tornado can change. Natural tornadoes are widely varied due to atmospheric instabilities, and unsteadiness of natural air currents, which is a phenomenon that cannot be simulated inside the exhibition space. However, the exhibit will be able to show children how the basic shape of the tornado can change with increasing or decreasing wind speeds.

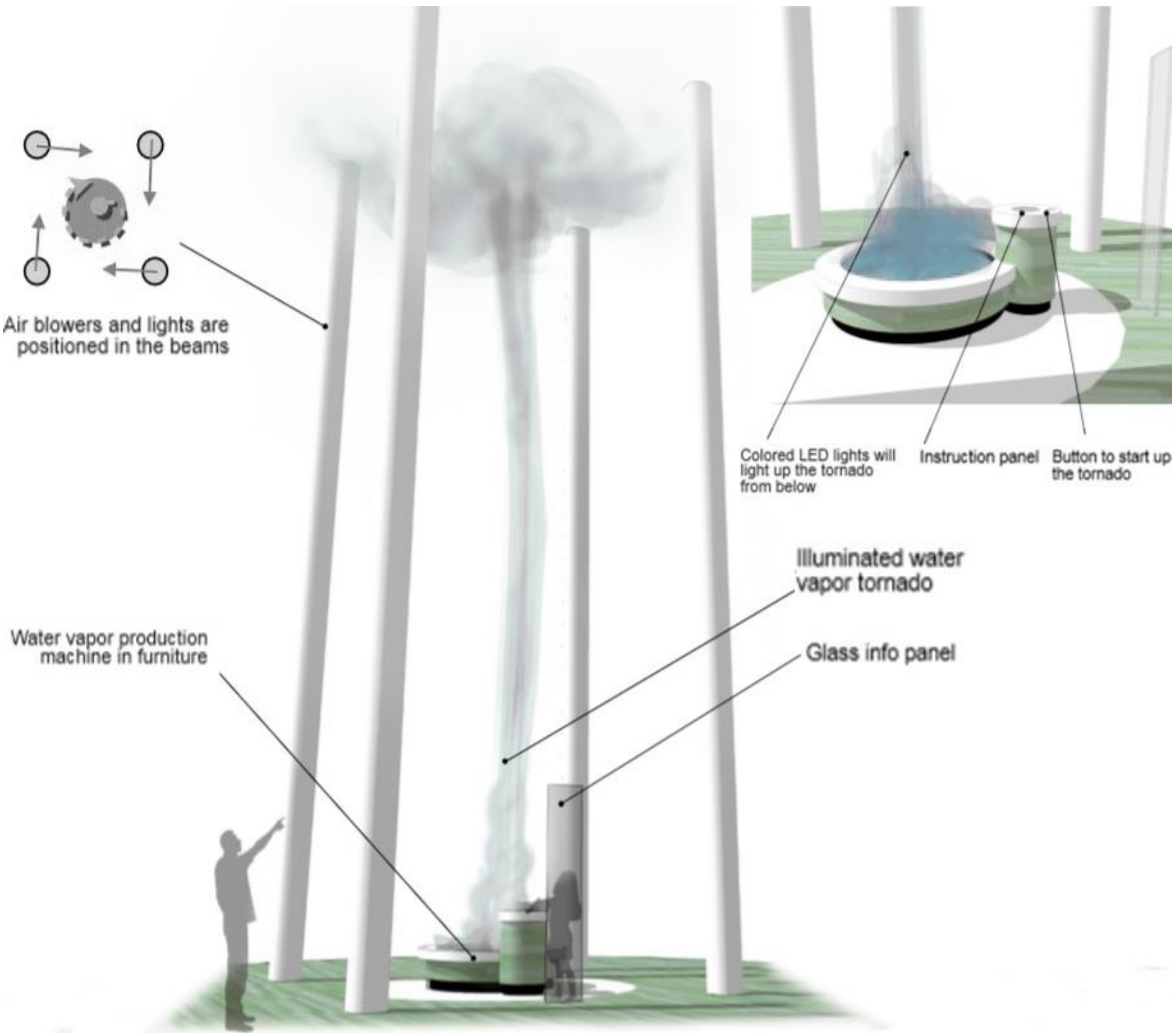


Fig. 7.4.2-1: The technological diagram of the exhibit Air Tornado.

Fig. 7.4.2-2: The augmented space for the exhibit Air Tornado

Source: Photographed by the author, 2015.

Mars Exploration Experience

The Mars Exploration Experience includes the interactive media wall –*Mission to Mars* and an interactive game - *Mars Exploration Rover (MER).* Both exhibitions locate in Zoom F. The interactive wall (**Figure 7.4.2-3**) uses typical Spatial Augmented Reality (SAR) technologies, as the author has mentioned in **Chapter 4**, and uses the curved wall as the surface to project the digital story on. Visitors have the option to interact with this digital wall and learn fundamental pieces of knowledge about the Mars. There are 4 different individual interfaces on this interactive wall:

> **Theme 1:** How much would you weigh on Mars? The first interface of the wall provides the visitor a chance to weigh themselves on a specially labelled scale, and could test a set of labelled backpacks that simulate weight on Mars, the Moon and other planets.
>
> **Theme 2:** 3D Mars - Large 3D Panorama 3D glasses were provided for visitors to view a 20-foot-long poster of a stereoscopic panorama taken by the Exploration Rover on Mars. This stereo view from the navigation camera on NASA's Mars Exploration Rover Opportunity shows a vista across Endeavour Crater, with the rover's own shadow in the foreground. The view spans 216 compass degrees, from north at the left to south-southwest on the right.

Theme 3: Life on Mars: What might we find? – This part includes the scientist Chris Hallman sharing his research about theoretical life on Mars. As a playful ancillary activity, visitors can also choose to design their own Martian life forms with the touch table below the screen.

Theme 4: Mars Terrain - Visitors examined large image mosaics of the Mars's surface created by the scientist Frank Centinello, as well as globes of Mars showing topography (**Figure 7.4.2-4**). Hand lenses and descriptions of points of interest were provided by the THINKTANK. (Tender Document of the THINKTANK, 2012)

Apart from the interactive wall, another part of the Mars Exploration Experience includes a technology-based educational experience - *Mars Exploration Rover (MER).* According to Janine Eason, the Exhibitions and Learning Director at the THINKTANK, there are two objectives of the exhibit, firstly, "to show that rovers are tools for doing science by enabling visitors to act as mission scientists", using the exploration rover to conduct a science operation on Mars; secondly, "enabling visitors to appreciate the role of autonomy on board rovers". In fact, very few visitors realise that it takes a long time for radio messages to reach and return from Mars, according to Janice. Depending upon the relative positions of Earth and Mars in their orbits, it can take between 4 and 24 minutes for the message to get there (one-way only). The time was 13 min 48 seconds for the MER-Curiosity. Therefore, interactive dialogue with a Mars Rover is impossible – to complete one set of instructions would take far too long. Remote crafts are increasingly being designed to take their own decisions (make up their own minds). However, some instruction is still necessary. This game is designed to show that a sequence of instructions has to be sent together as a package.

With this exhibit, museum visitors need to send instructions to the Rover to make a journey to take a photograph of a surface feature. The photograph is sent back to the player control screen. MER movements are controlled by touchscreen controls including a location grid, input button (forward, turn right or left) and a send button. The current position of the Rover is indicated on the grid, and the aim is to send the rover to a given target to take a photograph and return to base. There is a scale on the Martian surface in the diorama to give the player an idea of what value to enter, as shown in **Figure 7.4.2-4**. A series of moves including turns are required to complete the task. The visitor inputs a sequence of moves. After each instruction i.e. move forward, turn right, turn left, the rover moves a fixed given distance. The aim of the player is to put the rover in the correct position to take the photograph. When the rover is in the correct position the instruction to take the photograph is sent (as part of the sequence). Due to the time is taken for the instructions to reach the MER, the sequence of instructions must be sent together as a package. A clock on the control panel shows the time being taken. The clock will not work in real time. It must be speeded up to ensure that the game is played quickly. The whole manoeuvre must be completed within a maximum number of steps (to avoid the game going on too long). The game software also includes failsafe provisions, for example, when the rover has been programmed into a danger area, like unclimbable rocks, it must stop at the bottom and return to base. Failure message will be displayed on the screen. The Rover will also be programmed to return to base for recharging automatically to avoid high maintenance levels.

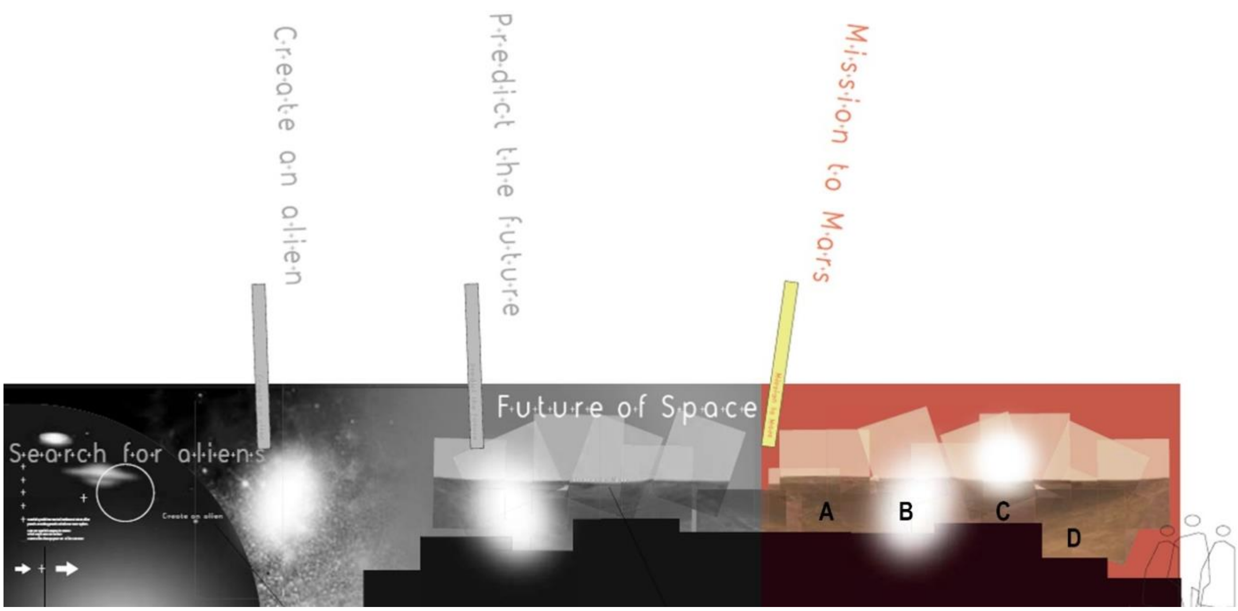


Fig. 7.4.2-3: Mission to Mars on the interactive wall, with A, B, C, D indicate theme 1-4.

Source: Edited by the author, 2015.

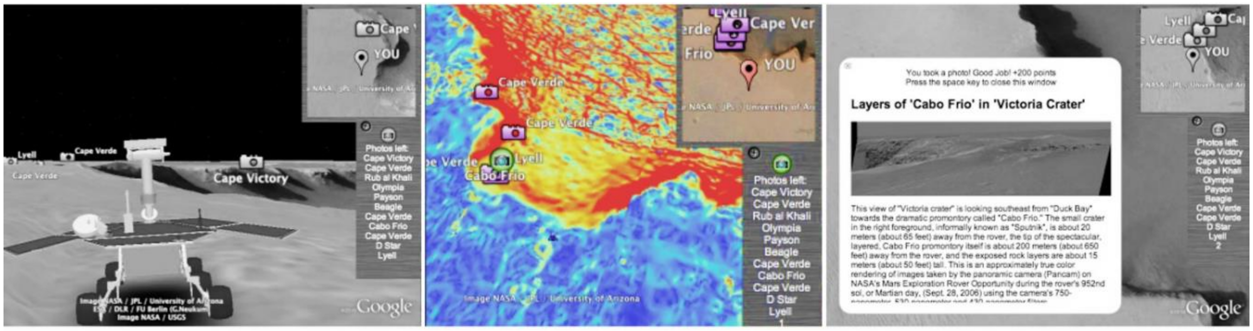


Fig. 7.4.2-4: Interfaces of the exhibit wall- Explore Mars

Source: Photographed by the author, 2015.

Fig. 7.4.2-5: The augmented space for Mars Exploration experience

Source: Photographed by the author, 2015.

Through analysing two feature augmented spaces inside the MAGNA and THINKTANK, there are four main design features between these two augmented space designs, which greatly maximised the museum experience and contributed to create those fun and educational interactions between the digital and physical layers, it includes:

1) **Providing attractive visual interfaces and unique physical interactions** – in the first augmented space design for the *Air Tornado* Experience, the visitors are invited to control the shape and colour of the Tornado by interacting with a LED touch screen, and they can physically experience the simulated air tornado by walking through that Tornado they created. In the second experience - *Mars Exploration*, a

consistent colour palette is used to unify those screens on the interactive wall. Static and animated elements on the screen are designed to provide focal points for the users depending on the actions required, those consistent, clear typographies provide strong visual hierarchy and improve readability.

2) **Clear interaction cues** – both augmented spaces provide direct physical orientation and real-time feedback, for example, the default screen display of each kiosk is on a loop that provides a visual overview of the impending mission and what the user might be expected to do, and linear interaction follows as the mission is progressively disclosed to the museum visitors.

3) **Embedding technologies for spatial perception and interaction** – in the first augmented space, the *Air Tornado* experience is created by 48 ultrasonic misting foggers and four giant fans in the ceiling, and LED lights and air blowers are positioned in the beams. In the second experience - *Mars Exploration*, spatial interaction around the interactive wall is communicating the 360-degree nature of the panoramic image, which provides feedback and helps users interpret the orthographic map.

4) **Real-time feedback** - there are several 'mission builder' screen displays created to reinforce the educational aspects of mission building. For example, in MER exhibit of the Mars Exploration, the display tracks user's progress in real-time until they are ready to submit the mission to the rover, as the rover executes the mission, a rover's eye view camera allows the visitor to experience the mission from the rover's perspective. The 'Rover Mission' sub-window at bottom right remains during execution, providing data regarding rover operations, distance travelled and angles turned.

7.5 Conclusion

In this chapter, the author has presented a selection of the data collected from Magna Science Adventure Centre and Thinktank, Birmingham Science Museum; in order to show interesting episodes of museum visitors and their interaction with augmented space, and the overall museum experience by those innovative narrations inside science Museums. In fact, reflections on these interaction episodes in the museum led to the definition of a series of corresponding "design sensitivities" for informing the narration of augmented space inside science museum. It is understandable that the data documenting people's experiences cannot be easily translated into specific "guidelines" or "requirements". However, the 'sensitivities' here suggest relevant issues and inspire creative design, rather than imposing rigid rules on the design. Sensitivities do not impose pre-determined solutions, but rather define spaces for discussion on how the design of augmented space could deal with the issues that they express. The main design sensitivities emerged from case studies are as follows:

For exhibition narration:

- Being a space where active engagement is supported, the interactive exhibition inside science museums should present, elements that provoke feelings of comfort and friendliness thus encouraging people to participate. In another word, the look and feel of the space should encourage the visitors to perform activities such as debate, exploration and discussion.
- To keep the user's interest and engagement high, ways to support different "layers of activity" with digitally augmented technologies should be envisaged. Participants should have the possibility to engage with the exhibition in a flexible, non-prescriptive way, to decide the level of their involvement in the exhibition. Each interactive element of the exhibition should provide successive surprises and discoveries for the visitors.
- The exhibition should provide the possibility of collaborative discovery and of making comparisons in order to support collaborative understanding and discussion of objects. As we observed during those two augmented spaces, the interactivity supported by the exhibition should not be limited to that between individual and exhibit, but we should consider the different degrees and combinations of verbal and gestural interaction amongst individuals.

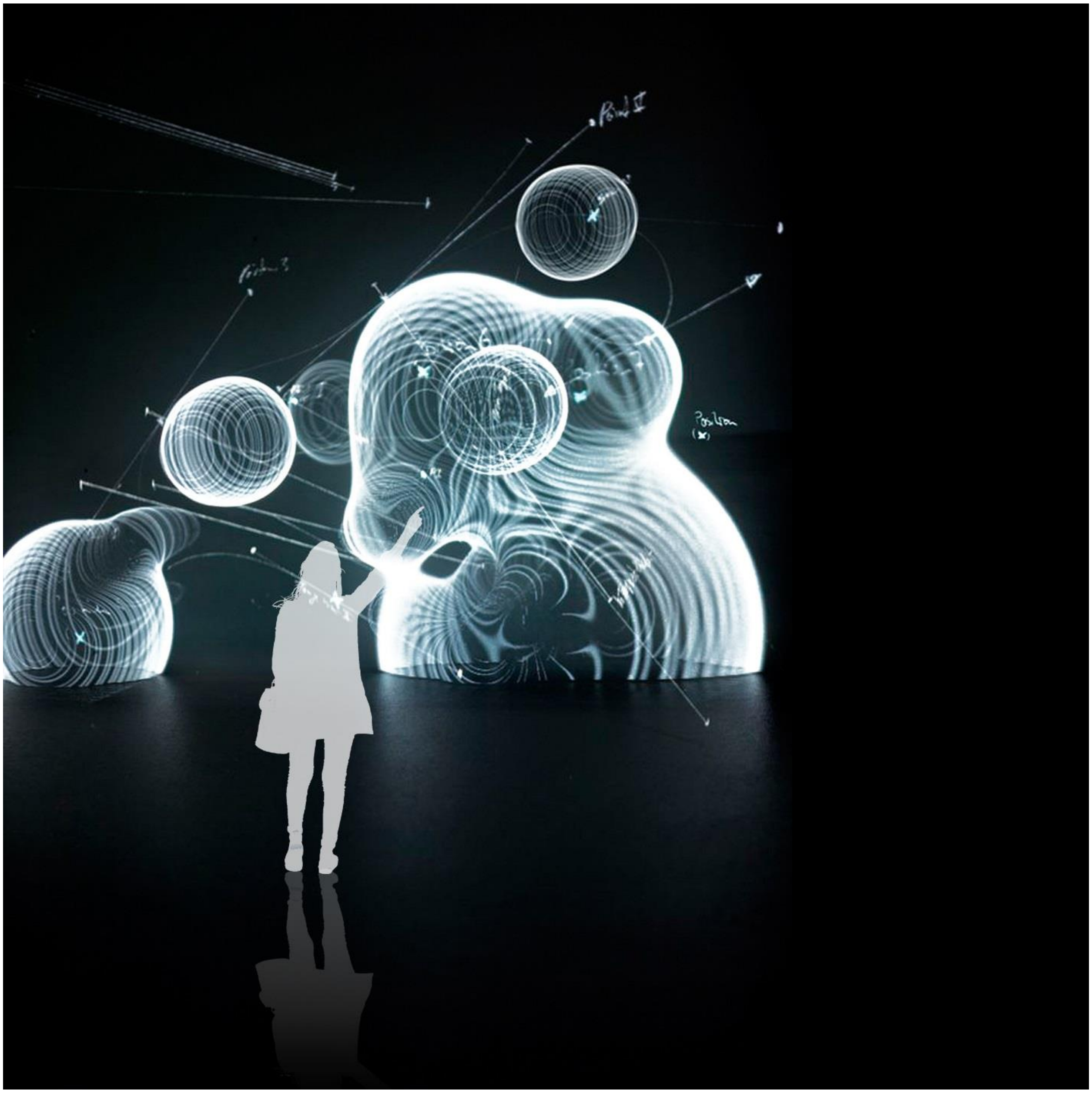
For augmented space design:

- The AR system of the augmented space needs to accommodate different user groups and people of all ages, appeals to children and adults alike. The exhibition should also support interaction from visitors with different levels of knowledge and expertise about the Collection, and involve equally visitors with different degrees of knowledge and interest.

- The designed augmented space should also give children the possibility to lead the process of discovery and to communicate their findings to their companions, which makes sure that each individual from the family group will be encouraged to take part to the activity around the augmented space.
- The augmented space should support the group visit experience with appropriate. The possibility for the visitors to talk to each other must also be ensured, as discussing the objects together is an essential part of the group experience. It should dawn upon museum designers that devices as HDM (Head Mounted Displays) or headphones are not appropriate for such space, and they need to avoid designing singular human-computer interface which isolate each museum visitor as well.
- The interaction design of the augmented space should provide unique and attractive visual interfaces, spatial perception and physical interaction, which showing clear clues, triggers and adequate affordances to make visible which actions the visitors are allowed to perform on each component of the embodied hybrid space.

Two museum cases (THINKTANK & MAGNA) and their analytical studies interconnected museum experience and exhibition design development. And this chapter also provides detailed 'design sensitivities' for both interactive exhibition narration and augmented space design, which copes well with the complexities of embodied hybrid space design. These 'design sensitivities' provide inspiration, but also clearly leave an ample open space for designers to creatively develop the interactive exhibition and new augmented space. Of course, ensuring that these sensitivities will take shape in the design of the exhibition does not mean that we can "predict" how users will interact with it and experience it. It is important to design for possibilities, to provide the opportunities for experience.

In the next chapter - **chapter 8,** the author will discuss how the Design-based Research (DBR) inside Hong Kong Space Museum moves from design sensitivities to the actual implementation for this renewed exhibition design project.



Chapter 8.

Design-based Research

Figure: Visitor experience inside Hong Kong Space Centre, illustrated by the author

Chapter8. Design-based Research

8.1 Chapter Overview

This design-based research was conducted during the 2^{nd} - 3^{rd} year of my PhD study, it was a part of the design project for Hong Kong Space Museum. And this practical project in the museum design industry became a great opportunity for me to adopt the 'design sensitivities' which the author generated from case studies, combining with work practice in the real world, transferring the knowledge from previous cases to current one. The original Hong Kong Space Museum (HKsM) was completed and officially opened to the public on 8th October, the year of 1980, it has 37 years' history until now. The post-2000 exhibitions have once been very successful and well received by the public and the museum community. However, a large part of the exhibitions was static and didactic. Moreover, museum visitors today expect and demand greater interactivity than in the past. With this project, our design team seeks and implements a greater understanding of the augmented space, current museum visitors and what type of interactives are most effective in enhancing presentation and interpretation of content for these visitors. To re-attract visitors with a more interactive and immersive exhibition environment, by adopting technologies like digital displays, sensor projections and registering system. In addition to that, multi-media resources and multi-channel social media strategies will also be enforced to create live performances and augmented environments. We want to create this robust, yet flexible, framework within which to pursue exhibitions and the visitor experience that will facilitate attentiveness to the current museum world, and build on the foundation of superb exhibitions and education programs that have made the HKsM one of the world's great astronomy and space museums.

The research is based on two years of discussions, exercises, surveys, and study that have involved the entire HKsM project by all staff. The research phase produced an extensive and broad range of ideas, views, and suggested plans. The results of these discussions and planning efforts are distilled in this plan and represent a consensus of the essential elements needed for sound exhibition design and development and the interpretive direction the museum desires to carry forward.

8.2 Internal Analysis

8.2.1 Museum background and context

Fig 8.2.1-1. The location of HKsM, which situated at the seaside of Tsim Sha Tsui in Kowloon

Source: Schematic map of Hong Kong 2015, edited by researcher

The HKsM (Abbreviated as HKsM) is located strategically at the seaside of Tsim Sha Tsui in Kowloon, next to the Hong Kong Museum of Art and Hong Kong Cultural Centre (**Figure 8.2.1-1**). This 8,000-square metre Museum has celebrated mankind's exploration of space since 1980, including the first planetarium in Asia. And it is currently managed by the Leisure and Cultural Services Department of the Hong Kong Government[23] (Gov.HK, 2015). The idea of a planetarium was originally proposed in the year of 1961 by the Urban Council, and in the year of 1971, according to the Triposo Guild, The Urban Services Department set up a working group to study overseas experience in establishing planetariums, which was aimed at laying the groundwork for HKsM (Triposo, 2013). Two years after, the Hong Kong Government located the

[23] The Leisure and Cultural Services Department (Chinese: 康樂及文化事務署, often abbreviated as LCSD, is a department in the Government of Hong Kong. It provides leisure and cultural activities for the people of Hong Kong, and manages various public facilities around Hong Kong including public libraries, swimming pools, and sports centres. The well-known Hong Kong Cultural Centre and Hong Kong Space Museum are among several museums also managed by the department.

building at Tsim Sha Tsui, and immediately started the foundation work. The museum was completed and officially opened on 7th October and opened to the public on 8th October, the year of 1980 (LCSD, 2004).

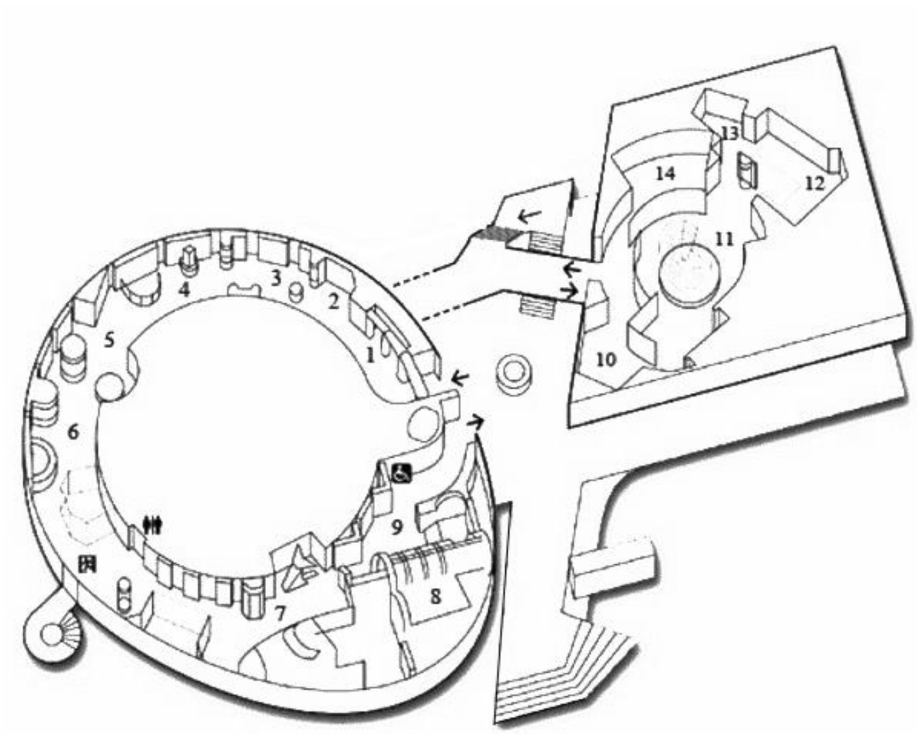


Fig 8.2.1-2. The original museum plan, which includes two thematic exhibition halls: the Hall of Space Science on the left side of this picture (east wing) and the Hall of Astronomy on the right (west wing)

Source: Plan from www.lcsd.gov.hk

HKsM was originally divided into two wings (**Figure 8.2.1-2**), the east wing houses the world's first fully automated planetarium, the egg-shaped dome covers more than 8,000 square metres, since its inception it has become a landmark in Hong Kong's cultural landscape. Beside the planetarium, there's also a space theatre, which boasts the first OMNIMAX [24] cinema in the eastern hemisphere, and the former exhibition gallery called the hall of Space Science. In the west wing, visitors can access the hall of Astronomy and a separated lecture room (Gov.HK, 2015). Both exhibition halls include predominantly participatory displays, and organises a range of activities for learning and pleasure throughout the year.

[24] The dome system, called OMNIMAX, uses films shot with a camera equipped with a fisheye lens that squeeses a highly distorted 180° field of view onto the 65 mm IMAX film.

8.2.2 A brief history of pass exhibitions

The initial interpretive strategy of those exhibitions in HKsM was to get as many items from this peerless aerospace collection on display and tell the basic story of the technology. A major effort to prepare airplanes and spacecraft for display was undertaken by the Collections Department and curators, and a great many key artefacts were treated and installed by opening day. It was a remarkable effort by the collections care staff. The curatorial and exhibition staff charted the topical layout of the two exhibition galleries in the new building. Generally speaking, it reflected a chronological telling of the story, focusing on key events and artefacts in the development of aerospace technology, or major historical events such as World War II or the Apollo Moon landings. As was reflected in the historical scholarship of the period, there was a content emphasis on the engineering development of aerospace technology and its operational history. This was not exclusively so, as the Museum opened with a dedicated art gallery and an art curator was added to the staff. Also, there were exhibitions in 1993 such as '*飞行益处 Benefits from Flight*' (later renamed Social Impact of Flight), which touched on how flight had changed the world in broad ways. That gallery even had exhibits designed specifically for children with doors they could open to explore the process of aircraft manufacturing, and the whimsical "Technology Transfer Machine," showing youngsters how aerospace technology was incorporated into other aspects of life.

Still, despite these notable exceptions, the overall presentation was largely focused on telling the exciting and inspirational story of how aerospace technology developed, with emphasis on the then standard technological progress narrative. The interactive exhibitry back then also reflected the standards of time. They were largely artefacts in display cases, with photographs and wall graphics supporting the label text. There were a few rudimentary mechanical interactives, such as flight simulators the public could operate, but by and large the exhibitions were static and didactic.

After the opening in 1980, the exhibitions in HKsM were always viewed as placeholders until there was time to replace them with more thorough treatments or with important topics not addressed in the initial offering. This first generation of HKsM exhibitions appeared around 1990. They included treatment of the early history of flight up to 1914, the early era of jet aviation, observation of the Earth, and the history of astronomy, to name a few. These exhibitions had solid content and represented exhibition techniques of the day. Several of them are still in place until the end of 2012 and do hold up well in terms of content. They do lack interactivity and other hallmarks of modern exhibitions, but still receive positive reviews in visitor surveys (based on travel website like Tripadvisor). A few have had web presence added well after they opened, but generally these exhibitions remain in the style and format from the era in which they were created.

As the premier air and space museum in Hong Kong during its first two decades (1980-2000) was the growth of aerospace history as an academic discipline. Also in this period, the history of technology broadened in general with the inclusion of social and cultural aspects of technology, political context, business history, and other themes that placed the history of technology in a framework of human endeavour in a wider way than traditionally had been the case. The exhibitions also reflected this broadening interpretation of aerospace history. For example, '*一战与航空航天 First World War in the Air*' addressed the traditional stories of the gallant fighter aces and compared that to the reality of the experience of air combat in World War I, and looked at how those myths survive in popular culture about the war. The gallery did a very good job of bringing current academic scholarship about World War I aviation into a public presentation in a museum exhibition. The Museum's reinterpretation of the V-2 rocket was another step in this direction, adding the important historical context of the wartime development of the V-2 as a weapon. The original exhibition script for the display of the Boeing B-29 engaged the topic from a range of perspectives and weighed the complexities of the story based on extensive historical scholarship. This version of the exhibition was not realised because of heated political controversy surrounding the project, and a much less rigorous treatment of the topic is what finally went on public display, but the planning for the exhibition nevertheless did reflect the museum's trend toward greater attention to academic scholarship in HKsM's exhibitions. However, these exhibitions still were fairly traditional in exhibit presentation technique—exhibit panels, artefacts in cases, films—but broke new interpretive ground by broadening the context of aviation and spaceflight history and presenting ways of making it relevant and interesting for those visitors who were not expressly interested in aircraft and spacecraft or just the story of the technology itself.

The second generation (around 2000) of HKsM exhibitions charted fresh territory with new exhibition techniques such as computer and more imaginative mechanical interactives, a more sophisticated web presence, education programming being developed in conjunction with the exhibition itself (as opposed to being created after the fact), and distance learning efforts to bring the exhibition interpretation into schools and other venues remote from the Museum. The first significant effort in this regard was the *How Things Fly* exhibition, which opened in 2006. Entirely comprised of science interactives and demonstrations by students called Explainers, '*飞行原理 | How Things Fly' explore*s the principles of flight, aerodynamics, control, materials, structures, and other aspects of how aircraft fly and are designed and built. Subsequent exhibitions such as '*飞离地球 | Moving beyond Earth'* (2009), '*飞行先驱 | Pioneers of Flight* (2010)', *'探索宇宙 | Explore the Universe'* (2011-2012) and '*时空与航行 | Time and Navigation'* (2013), all represent this broadening of content interpretation to include social and cultural history, and modernising of exhibit presentation techniques that have taken place since the museum opened in 1980. These exhibitions also saw the emergence of integrating the web and social media as a new mode of interpretation, learning engagement, and audience involvement. These exhibitions also employed some level of front-end visitor evaluation and visitor surveys of the final product. More extensive and systematic evaluation should and will be part of the future HKsM exhibition development and execution, but the importance of this aspect of exhibition planning was established with some precedent in the last decade.

This brief overview of the HKsM exhibition program demonstrates that it has always been thoughtful and carefully planned and executed. It has always been quite popular with museum visitors. And, it has always evolved with broadening approaches to content and interpretation, new techniques and technologies of exhibit presentation, and greater audience engagement and involvement. This process will continue. The interpretive plan of the new HKsM from HKD studio evolved with the incorporation of relevant new contextual content themes to broaden the understanding of, and widen audience appeal, for the core subject and interactive collections of aerospace technology.

8.2.3 A study of current visitor experience

As one of the most visited museums in Hong Kong, according to the 'Concept Development Report' from HKD studio: "With as many as 50,000 people visiting HKsM on a weekly basis, continuous concourses are crucial for circulating visitors through the exhibits. The concourse divides the museum into two parts. The west side of the building - *the Hall of Astronomy* contains the smaller and more theatrical exhibits, while the east side – *the Hall of Space Science* houses larger exhibits. The formal curator Mr. Chun-lam Chan believed that good visitor circulation through the galleries was critical to the success of the museum. He remarked, "The solution evolved from studying the potential movement of people through the museum…This circulation pattern allows the visitor to quickly understand where he can go to view the various displays. The experience of the museum was not limited to the interior spaces. Chun-lam hoped to encourage an active participation by the public and he hoped to open the interior of the building up to the exterior with large expanses of glass, making the planes and other aircraft legible from the outside of HKsM. He commented: "Within the sky lighted, glass-fronted galleries with open steel trusses, the visitor will view exhibits which visually relate to the sky and greenery outdoors. Variations in the height of the separate display areas emphasise the transition from open to the enclosed gallery."

About 70 percent of visitors enter the building from the Hong Kong Cultural Centre directly into the museum hall, which serves as an entry space as well as an exhibit gallery. The high number of people moving through the space and touching the displays is hard on the exhibits. Anything that goes on display, especially interactive exhibits, must be robustly constructed. Since people don't file past an admission booth, they don't receive any personal orientation to the space—no floor plan offered to them or directions provided. The museum's welcome centre, which provides these services, is centrally located, but visiting it is optional. Visitors will, more often than not, wander through the Museum without guidance. Wayfinding signage and floor plan maps can be found on the walls in several places, but it is uncertain how much visitors use them. It is important for gallery entrances to clearly indicate their subject matter with an introductory panel, provide a website link, and credit exhibit donors.

Visitor evaluation has been done on an as-needed basis. Results vary depending on the time of year, but several consistent trends have emerged:

- Slightly more than half of the visitors are visiting the Hong Kong Space Museum for the first time.
- The split between male and female is about even over the course of a year.
- About 20–25 percent visit alone.
- About 55-67 percent of visitors are children (Under the age of 13).
- About 17–40 percent, depending on the time of year, are from foreign countries (outside China).

Apart from that, a number of the museum's exhibits have been criticised for containing outdated information, including describing space projects in the 1990s as future ones. (Chen, 2015). As the audit review conducted by Hong Kong Leisure and Cultural Services Department, it notes that, it had the lowest overall satisfaction level (i.e. very/quite satisfied) of 73.9% among the seven LCSD museums[25] (Chai, 2006), with lowest satisfaction levels of 78% for facilities and 76.1% for exhibitions (LCSD, 2004).

Nowadays, museum visitors today expect and demand greater interactivity than in the past. While the museum strives to meet their expectations, and produce exhibitions that appeal to the varied learning styles of a broad audience, the sheer number of visitors, and the destructive behaviour of some, make this problematic. Every exhibit must be designed and produced with heavy usage in mind, and artefacts must be securely protected while on display. Ongoing routine maintenance of exhibits and galleries is crucial to keeping the museum and displays in a condition befitting a prestigious city institution. This is a never-ending challenge.

8.2.4 The starting point for museum renovation

In the year of 2014, with the aim to change physical spaces towards more immersive and satisfying learning environments, in the meanwhile enable visitors to learn the latest updates about aviation, astronomy and

[25] The LCSD (Leisure and Cultural Services Department) manages seven major museums: the Hong Kong Museum of Art, the Hong Kong Museum of History, the Hong Kong Museum of Coastal Defence, the Hong Kong Science Museum, the Hong Kong Space Museum, the Hong Kong Heritage Museum, and the Dr Sun Yat-sen Museum. Their roles are to acquire, conserve, research, exhibit and interpret both Hong Kong's tangible and its intangible cultural heritage.

space science, two permanent exhibition halls in HKsM were closed for replacement of exhibits and renovation work. According to the annual report of HKsM at the beginning of 2014, it mentioned that the intention of this big renovation project was to do something new, and a new museology requires a new space approach. They dreamt of a museum not as a space to visit but as a space in which to discover, as a "transparent" museum, a museum of great museo-graphic emblems signposting rich, multi-disciplinary contents about space exploration and active and immersive visiting experience. (The Annual Report of HKsM, 2012, Accessed 15/06/2015)

This renovation project was designed and delivered by HKD studio and Purcell[26] (Hong Kong office) from the year of 2014. Those two exhibition galleries will be renamed as the "Hall of the Cosmos" and "Hall of Space Exploration" with a total area of 1,600 square meters, about 100 sets of new exhibits will be installed in the two halls, of which about 70 percent are interactive exhibits, for simulating the novel experience of travelling through space and time (Houghton, 2015).

> …visitors may stand on surfing boards to venture through different objects in space to understand the warping of space by gravity or they may enter an upside down virtual space station to experience the disorientation feeling in the weightlessness environment in space.
>
> (Tender document by HKD studio, 2015)

The previous exhibitions in HKsM were focused on the history and theory of Astronomy, Space & Aviation, exhibitions have been the product of extensive and careful planning, for the most part they have not reflected an overall conceptualisation of the subject as expressed in the whole building or with the entire visitor experience in mind. The post-2000 exhibitions have been very successful and well received by the public and the museum community. However, with models and explanations provided by storyboards and interpretive devices, those displays are generally not changed ever since. In looking to the future, giving consideration to the rapidly changing museum environment, the public's more diversified expectations and

[26] Purcell is an architectural design practice with 15 regional studios in the UK and four studios in Asia Pacific. It works across eight sectors: education, hospitality, places of worship, public, residential, transport, workplace and culture.

increasingly splintered focus of their leisure and educational time, as well as the altered and more competitive fund-raising landscape, this is an appropriate time for HKsM to reassess its exhibition program.

This renovation design project was commissioned in the year of 2015. As the author details the Proposed Work Plan and Project Summary for the HKsM in **Appendix 5 & 5.1**, this project is divided into 6 tasks: Conceptual Design, Preliminary Design, Final Design, Fabrication & Production, Installations and Integrated Design. As shown in **Figure 8.2.4-1**.

Task 1	**Task 2**	**Task 3**	**Task 4**	**Task 5**	**Task6**
Conceptual Design	Preliminary Design	Final Design	Fabrication and Production	Installations	Integrated Augmented Design
Equivalent to RIBA stages 1-2	Equivalent to RIBA stage 3	Equivalent to RIBA stage 4	Equivalent to RIBA stage 5	Equivalent to RIBA stage 6	

Fig. 8.2.4-1. HKsM project is divided into 6 work tasks, from conceptual design to integrated design.
Source: Based on the work plan from HKD Studio, edited by the author.

8.2.5 The roles and responsibilities of the design team

The core team of the Hong Kong Space Museum (HKsM) consists of the lead curator, lead educator, museum designers and the project manager. These team members lead regularly scheduled meetings and have approval authority in most of the project daily activities.

Curator/Content Expert – Knowledgeable in subject matters. Conceives exhibition idea, researches content, selects artefacts, writes the content document for exhibition development. Works with exhibition team on the concept and ensures that content interpretation is accurate. The curator for HKsM project is Mr. Richard Houghton from HKD studio.

Exhibit Design Manager – The Exhibit Design Manager (DM) is responsible for the look and feel of the exhibit space and the physical interpretation of the concept. The DM has knowledge of three-dimensional design and skill in creating two and three-dimensional drawings and models. The DM translates complex subject matter into physical accessible, intellectually educational, and visually aesthetic space that communicates messages and themes. When the design is contracted the DM works with Project Manager to manage the design process and deliverables from the contractor.

Project Manager – The Project Manager (PM) is the leader of the Project Delivery Team (PDT). He/she manages scope, schedule, quality, and budget while leading a PDT to successful project execution. This individual is the primary interface in projects between the museum departments and the primary internal advocate for the specific project. PMs manage all project resources, information, and commitments, and integrate and focus the efforts of the PDT.

Educator – Educators advocate for diverse audiences and establish learning objectives and take-away messages. They plan for various stages of evaluation, research and write labels with the emphasis on active learning, develop interactives, and work to ensure the space meets programming requirements. Our global team in the UK and Hong Kong also includes those who may have input at various stages of the project, internal and external stakeholders, and anyone who has an interest in regular or semi-regular communication.

Writer – Knowledge of history and/or science. Translates complex subject matter into exhibit labels for intended audiences. Works with the team on exhibit concept and is responsible for content interpretation and label script.

Exhibit Designer – Knowledge of three-dimensional design. Physically and visually translates complex subject matter into spaces that communicate messages and themes. Works with exhibit team on the concept and is responsible for the look and feel of the exhibit space and the physical interpretation of the concept.

Graphic Designer – Knowledge of two-dimensional design. Through the use of colour, typography, and illustration, creates graphics that translate complex subject matter into layouts that communicate exhibit messages and themes. Is responsible for the graphic interpretation of the concept—the interface between the content and the visitor.

Exhibit Technologies – Designs, develops, installs, and maintains state-of-the-art technologies and mechanical interactives in Museum exhibits, provides technical support for outreach programs, and manages networked building lighting and communications systems. Team members have knowledge of state-of-the-art technologies used in museum and public education environments, including development, installation, and maintenance of new, custom computer interactive or conventional multimedia exhibition components, such as audio-video kiosks; specialised mechanical and electromechanical interactives; specialised electronic circuits, computer databases, and electronic control and data acquisition systems; Internet and LAN (Local Area Network) configuration; digital video production, editing, and post-edit formats; digital assets storage and management; and computer-based and network control systems. They also have knowledge of collections care and preservation issues as they relate to exhibit design, lighting, installation/dismantling, and maintenance.

Exhibit Production – Exhibit graphic uses digital files provided by the graphic designer to produce and install finished graphics, such as labels, panels, and murals. Exhibit fabrication builds and installs artefact cases, risers, panel substrate, walls, and other structures required by the drawing package and provided by the exhibit designer. The artefact mount-maker fabricates and installs mounting devices of different materials for the effective display of artefacts using information provided by the exhibition designers, curator and educators.

Digital Curator – Works with the exhibition team to conceptualise, design and develop digital experience. At the conceptual stage, Digital Curator responsible for researching, gathering, and managing all digital content assets (images, video, audio, etc.) and works with content ideas and learning objectives to envision and design interactive experiences for onsite and online audiences. Digital Experiences also works with exhibit teams to envision and develop in-gallery digital experiences, opportunities for onsite audience engagement, and ways to bridge the onsite and online visitor experience. Digital Experiences provides a process for internal conceptual development and design (identify target audience, learning objectives, conceptual plan, user/visitor experience narrative, audience engagement plan, creating content for a digital audience/context, wireframes, storyboards, prototypes, visitor testing, technology selection, design and build, content maintenance planning), outsourced digital design and procurement.

All the work was delivered in HKD studio, UK and approved by the Museum director in Hong Kong Space Museum. Besides working as a curator and senior exhibition designer for this HKsM project, the author is also in charge of sourcing and developing the content for interactive exhibits that highlight recent discoveries in aviation and astronomy world. The author has organised periodic meetings with the museum curator, project manager and education officer in order to inform them of the progress of the design work and to share with them the most significant results of my studies. Early design ideas were also discussed and commented in these group sessions held at the studio. Documentation from the HKsM object archive and library was also available to us to support those sessions.

Those design concept sessions were often followed by a group brainstorming inside the design group, where researchers on the project and members of the education department commented on the results of the study and proposed design ideas. The production of storyboards and scenarios followed: we explored each "theme" that emerged from the conversations and explored its relevance and appropriateness for a possible exhibit and augmented space inside the exhibition gallery – the Hall of the Cosmos. The design team listed a series of keywords and key-concepts emerging from field studies, combined with the formal design sensitivities which emerged from my case studies, and brainstormed on their possible relationships to visitors' activities and exhibition features. This exercise proved particularly useful in encouraging designers and museum participants to think creatively about the narrative design, as shown in **Figure 8.2.5-1**.

The concept design and primary design of the project started from August 2014 to Mar 2015, as shown in **Appendix 5.1 – Project Summary for HKsM.** The detailed exhibition narrative development will be presented in the following subsection.

Fig 8.2.5-1. Design making process represented through different activities

- Inspiring images (top-left) – Images collected for inspiration, directed by Content Expert and Exhibit Design Manager.
- Piles of images (top-right) – Piles of pre-selected images that exhibition designers carry around with them.
- Labelling piles (bottom-left) – Piles of images are labelled as brainstorming materials used during the design workshop, directed by the author.
- Giving a presentation (bottom-right) – An exhibit designer from HKD is presenting an interned layout setting for the Hall of the Cosmos, HKsM.

Source: Photographed by author.

8.3 Exhibition Narrative Development

8.3.1 Guiding principles of exhibition planning

In order to place the HKsM exhibition program on sound footing for the future, it is important to address key principles that underlie successful exhibitions. With the implication of those design sensitives generated from case studies, the exhibition planning and development were structured around a number of fundamental guidelines addressing interpretive strategies, visitor experience, and presentation philosophy based on these two elements. Some of these are longstanding elements of best practice that HKsM has incorporated in its exhibition process for many years. Others are newer ideas that reflect heightened design concepts and objectives from my previous cases to address visitor needs and fresh thinking about how to effectively reach the range of different visitor groups, and thus broaden the influence and impact of this space museum. In recent years, the museum profession has made a great effort to explicitly identify these principles and practices. Traditional ones have been revalidated, newer ones posited and tested, and all of them codified into a body of exhibition practice that is more coherent, and thus more usable to exhibition teams.

During the period of HKsM discussions preceding the preparation of this plan, a good deal of exchange took place regarding such principles. The following best practices represent a consensus that should guide the development of HKsM exhibitions. Not every principle is relevant to this specific exhibition, but they should be considered as a framework for developing every exhibition in the museum environment. They should become a working set of principles that informs all other exhibition works as well. Each project should be regularly tested against them as it evolves to ensure the final product will result in an exhibition that meets the high standards for which we strive.

Interpretive Strategies

During the first couple of decades after the 1980 HKsM opening, exhibitions were thought of largely as a local educational experience. Visitors came to the Museum, toured the galleries, enjoyed seeing the artefacts, and hopefully learned something. Ideally, they would be inspired to learn more on their own after their visit, or maybe even come back again. This scenario, of course, is still central to the visitor experience. But as the visitor experience has changed, as the way people engage with museums and museum content through other avenues, such as the web, has changed, we must think of the physical exhibition gallery differently. We must see the exhibition as only a single component of the entire visitor experience and develop it accordingly. Today, the visitor experience can begin before they arrive by checking out the museum on-line before coming, entail a variety of things in the building like specialised programming, and can continue after they leave with further on-line engagement. Moreover, the visitor experience is far more socially interactive than it once was. This includes not only accessing content digitally, but interacting with content experts, or sharing new information with content experts about the material on display, as examples. In short, the visitor experience is now so much broader than it traditionally was, when developing an exhibition, it must be understood as a component of a more comprehensive visitor experience and educational journey, one where the physical visit to the museum and the digital augmented engagement with a given exhibition, or the whole museum for that matter, is blurred.

All major exhibitions should be conceived and developed around a so-called "big idea", a theme or set of overarching messages that form the principal historical lessons or scientific insights we want to get across to visitors. As the museum designer, I want them to drill down as deeply as possible and learn as much as they can, but the big idea or key messages will provide a "minimum takeaway," as well as the framework on which to build a more detailed understanding of the subject if the visitor chooses. Where possible, the exhibition should strive for a "Wow! Factor" utilising striking artefacts, or a spectacular exhibit technique, all depends on its feasibility. Exhibition messages should be crafted to ensure content relevancy and exercise discipline and restraint in content presentation. Also, when effective or useful, exhibition teams should experiment with creative ways of organising content that move beyond traditional chronological or subject categorisations or object classifications. This should not be done just for the sake of being different. Sometimes more traditional approaches work best given the subject matter. But when an innovative way of organising and expressing information and ideas proves more effective, it should be pursued. Exhibition content should also benefit from user-contributions and dialog with potential audiences that can be facilitated by on-line, mobile, and social media interaction and feedback. Learning goals should be defined in terms of the takeaway messages to help evaluate the success of exhibitions.

Other key interpretive strategies are more established, but no less vital to a successful exhibition and must be integral to exhibition planning. HKsM is a centre of excellence for the history of aviation, spaceflight, and astronomy in China, and a leader in planetary science research. The exhibition program benefits greatly from having these leading content experts on staff. All HKsM exhibitions should strive to present the most up-to-date research in history and science, and/or our expert general knowledge of the subject matter. Leveraging these strengths should always be at the heart of our interpretive strategy.

Finally, and critically, we want to encourage new proposals that are conceived with the overall museum content goals and messages in mind. With those established new exhibits, the new narration should be developed with those goals and messages resonant in the content and presentation philosophy of the project. It just should be done so with an approach that can generally mesh with related content already on the museum floor. We want to take on new ideas and subject matter that stretches our exhibition program in interesting and effective ways, but at the same time we do not want to end up with a hodgepodge of distinct exhibition zones that do not relate well to one another. We cannot go back to the 1980s when we had a blank canvas and an empty museum to fill. Our finite resources and our need to serve our huge visitor(ship) necessitate revitalising exhibitions one or two projects at a time. The only way to produce a coherent presentation over time is to ensure each new project fits in some way within a broad interpretive plan, in terms of content themes, subject matter interpretation, and those interactive representations.

Visitor Experience

As noted under Interpretive Strategies, visitor experience needs to consider both what is within the physical walls of an exhibition gallery and what is to be experienced beyond. Let's begin with the physical layer of the gallery itself. Key to a successful visitor experience, especially in a museum with as large and wide-ranging an audience as HKsM, is variety. Not everyone is looking for the same experience, people learn in different ways, visitors come with different levels of knowledge and diverse backgrounds, and are comprised of differing social groups which govern how they use the Museum. To achieve success in a visitor environment such as HKsM's, variety is essential. Defining the specific audiences for individual exhibitions should be done early in the planning process, as it will govern many factors in the development of the exhibition—content, messages, design, interactives, etc. While we strive to have all exhibitions appeal to a general audience, attention should be paid to specific targeted audiences for each exhibition as well.

Exhibitions should offer a variety of presentation formats that accommodate a broad range of learning styles and engage as many senses as possible. The spectrum of visitors we need to serve in the millions that pass through our galleries entails all ages, education levels, interests, ethnicities, and so on. Moreover, as the author discussed in **Chapter 5.2,** not all visitors process information in the same way. To reach as many as possible, multiple presentation formats—text, visual, audio, tactile, etc.—should be employed where appropriate to deliver the ideas, information, and messages we want to convey. Content development should be approached with all these formats in mind. Label text should be presented in a tiered format, making major ideas down to detailed information accessible in an effective way at the discretion of the visitor. Family labels or directed learning labels should complement and support the main text to further increase audience accessibility to content. Interactive elements, digital and mechanical, should be created to support content and messages in an integrated way, providing a broadened learning experience. Similarly, touchable and audio features, and other innovative SAR technologies, should comprise the package of multiple presentation elements where useful. In short, exhibitions should provide a diversity of experiences and entrées to content to engage the broadest range of visitors possible.

Exhibitions should also create environments that are conducive to social interaction, both among visitors physically present in the gallery, as well as through digital social media. The visitor experience, for those who wish to avail themselves, can be a social experience within a group touring the gallery together, random visitor social engagement in the museum space, or through mobile devices with people not present in the gallery. The on-line features of the exhibition—website or other digital content—should be designed as seamless components of the presentation. The exhibition should be conceptualised as a single creative entity that is comprised of physical and digital elements, accessible and engaged with in a variety of ways.

Similarly, related outreach programming (in-gallery and distant), and other aspects of public engagement such as lectures and symposia should all be developed in conjunction and supportive of the exhibition. In short, all the elements discussed above should be thought of as "the exhibition", and developed with this sensitivity in mind. The traditional approach of building an exhibition gallery and then adding ancillary pieces such as education programming or a website, developed separately, is no longer viable in the multisensory, interconnected content delivery world of today. Exhibitions in this day and age must be attentive to the changing way people engage and absorb content. The exhibition visitor experience now must encompass a broad spectrum of elements and integrate them in creative ways to stimulate engagement, fulfil audience needs, make the experience participatory, and accomplish the museum's mission to commemorate, educate, and inspire.

Presentation Philosophy

Successfully implementing augmented space and interpretive strategies and creating a rich visitor experience is intimately bound with a number of crucial practical aspects of exhibition design and fabrication that must be part of the development process. Fundamentally, exhibitions need to be designed and built to balance the showcasing of collections and the digital integration. As noted under interpretive strategies, central to the purpose of the museum is to provide access and interpretation of carefully designed augmented spaces for the visitor. The objects are what they come to see. As such, curators, designers, and fabricators need to express their creativity in ways that also provide maximum safety for the artefacts—be it from environmental conditions such as light, or physical jeopardy such as damage or theft from visitors. Further, exhibitions should be designed and built so as to allow adequate access to artefacts for staff to perform repairing or updating work. Similarly, the physical design and construction should be attentive to uses of the gallery space beyond visitors touring the exhibition. Consideration should be given to programming and special event activities. Making galleries physically adaptable for different AR technology programming and broadcast outreach, as well as after-hours special event activity, is important to meeting those needs of the museum. No less important to creating exhibitions that are attentive to all these things at the outset is the ability to effectively and economically modify or upgrade exhibition elements over time, as well as perform required maintenance. Reasons would include content revision, technology upgrade, replacement of unsuccessful interactives, and the like. The initial project budget should include a line for maintenance and upgrades.

Another aspect of the physical nature of exhibitions that the museum needs to consider implementing the interpretive strategies and visitor experience goals outlined above is the basic architecture of the gallery spaces. We need to create a number of smaller and physically flexible exhibit spaces to broaden the variety of our presentation capability to meet desired content, education, and design goals. And the public spaces in the museum that are not expressly exhibition galleries should be considered carefully with regard to how visitors use them and how they complement and enhance the museum experience.

8.3.2 Content goals and educational messages

In the broadest terms, the content goal of the Hall of the Cosmos is to explore, and help our visitors understand the interconnections between the Cosmos, the development of aerospace technology & space exploration and the transformation of the human experience. The role of aerospace technology in this transformation has been profound, and thus demonstrates the significance of our collection, the relevance of our research, and the importance of the Museum.

To support this overarching purpose, five encompassing content goals will organise and shape our exhibition presentation. These goals cut across and can reference both history and science, both aviation and spaceflight. In the past, we have been largely compartmentalised by academic discipline and separated aeronautics and space. These content goals are designed to foster greater integration of history and science, of aeronautics and space, where appropriate and desirable, yet remain flexible enough to accommodate presentations that necessarily should maintain a narrower focus. Exhibitions do not need to include all these goals, or even mention them specifically. They are intended merely as organising principles to impart some form of coherency to our overall exhibition presentation. These content goals can also guide the general interpretive direction of the museum from research to education to collecting, even fund raising and promotion.

Content will be organised around the following for content goals:

1. **The Origin of the Universe** - The first and foremost content goal is focused on the origin of the Universe, the origin of things has always been a central concern for humanity. As Steiner said, "the most fundamental origin of them all would seem to be the origin of the universe as a whole – of everything that exists, without which there could be none of the creatures and things mentioned

above, including ourselves." (Steiner, 2006). In this introductory area, visitors begin at our own Milky Way galaxy and travel outward to billions of galaxies as far as our eyes can see. The question of how we fit into the vast web that is our universe has intrigued observers for many centuries. It is with modern tools and instruments that we are beginning to truly understand how vast the universe really is and how important our questions are.

2. **Beyond Earth: Exploration of the Solar System** - Central to our research agenda is the history of human spaceflight in the Apollo and shuttle eras. The heart of our science research is the exploration of the Moon and near planets. The history of astronomy and public programming utilising the public observatory are major museum initiatives. All these activities, and more, can be gathered under the content goal of human presence and exploration Beyond Earth. These stories are among the most compelling we have to tell and should always be part of our exhibition program.
3. **Imagination Flies: Invention, Innovation, Engineering, and Design** - This content goal entails our central story of the development of aerospace technology, emphasising invention and innovation in aeronautical technology, spacecraft and related systems, and instruments of planetary and astronomical research. It includes coverage of aerospace engineering and design, both technically and institutionally.
4. **The Personal Interface with Aerospace Technology** - This content goal will address a more inward view of aerospace technology. Stories that illuminate our individual experiences with aerospace will be captured under the rubric of 'I Can Fly'. Of course, general aviation, private flying, and sport aviation might be the most obvious forms of personal involvement with flight, but all of visitors likely will have some direct personal relationship to the technology. Be it simply flying on a commercial airliner, being taken for a ride in a private plane, being or having a family member who is an aerospace engineer, working in the aerospace industry, being present for the launch of a spacecraft, and on and on. Flight pervades nearly every facet of our lives. Our exhibitions should endeavour to enable visitors to relate to it in personal ways. This, of course, is a key avenue for one of the major aspects of our mission, namely, to inspire young people to consider aerospace and related STEM careers.

5. **Globalisation and the Influence of Aerospace Technology** - This content goal emphasises the globalising nature of aerospace technology. It is arguably the most international of technologies and its reach across the globe is profound. The commercial, military, economic, political, and cultural influences of flight have shaped the world from the outset and are a defining characteristic of the modern world. These are critical aspects of our story we must address in our exhibitions. All of us, from engineers and pilots who create and employ flight technology, to everyone who uses the technology or has their life influenced by it, are participants. From the military applications of aeronautics and space, to travel and commerce, to the impact on our daily lives, we are all, directly or indirectly, involved with flight. From the astronauts who travel to space, to the engineers and scientists who place the creations of humankind onto other worlds and beyond, we all collectively participate in these endeavours as a species. This content goal will encompass subjects that tell the story of how we all are influenced by aerospace technology and how our use of the technology continually reshapes the world.

These five encompassing content goals will enable the design team to organise and relate the content in creative ways, and if adhered to by individual projects, will move the museum's exhibition presentation toward a coherent program, offering relevant information, substantive messages, and memorable visitor experiences. To ensure our exhibitions meet this standard, a number of key interpretive themes should infuse our content goals. Attention to them will place the artefacts in context, enrich the historical narrative of the stories they illustrate, and provide visitors with tools to frame and pose their own questions.

The following key interpretive themes were also informed in content presentations:

- Aerospace engineering, design, industry, and manufacturing
- The impact of aerospace on daily life
- Personal connections to aerospace, including multifaceted careers
- Cultural aspects of aerospace, including social movements, popular culture, and artistic expression
- Engineering and scientific principles of flight

8.3.3 Emerging scenarios for the exhibition concept

A museum gallery of the scale of HKsM affords an arena where the storytelling is of great breadth and imagination. The possibilities for how we approach our subject matter are as limitless as the bounds of spaceflight itself. As such, the purpose of this exhibition plan is not to set down a prescriptive set of gallery topics and exhibit ideas. It is not intended to be a road map for a rigidly defined set of exhibitions to be executed. Rather, it is meant to be a useful framework that fosters creativity and innovative thinking, but does so in a way that shapes the content and messages we seek to impart in a broadly coherent way over time.

We want to present a narrative of space exploration that is intrinsically exciting, informative, inspirational, even moving at times. But we want to infuse that narrative with themes, ideas, and questions that lead our audiences to be reflective, contemplative, probing, and inquisitive about the period of history when humans gained their wings and first ventured beyond the atmosphere of Earth, and to ponder where our ingenuity and vision can or should take us next. What follows is a set of encompassing content goals and a palette of interpretive themes to guide us toward such a presentation in our exhibition program. From that perspective, it could serve as the Museum's general interpretive plan. Based on above guiding principles for exhibition planning in the Hall of the Cosmos, the overall interpretative plan was carefully considered, the proposal developed a thematic structure in delivering all the contents described in the brief of this gallery, and eventually arranged it into a complete storyline, as shown in **Figure 8.3.3-1.**

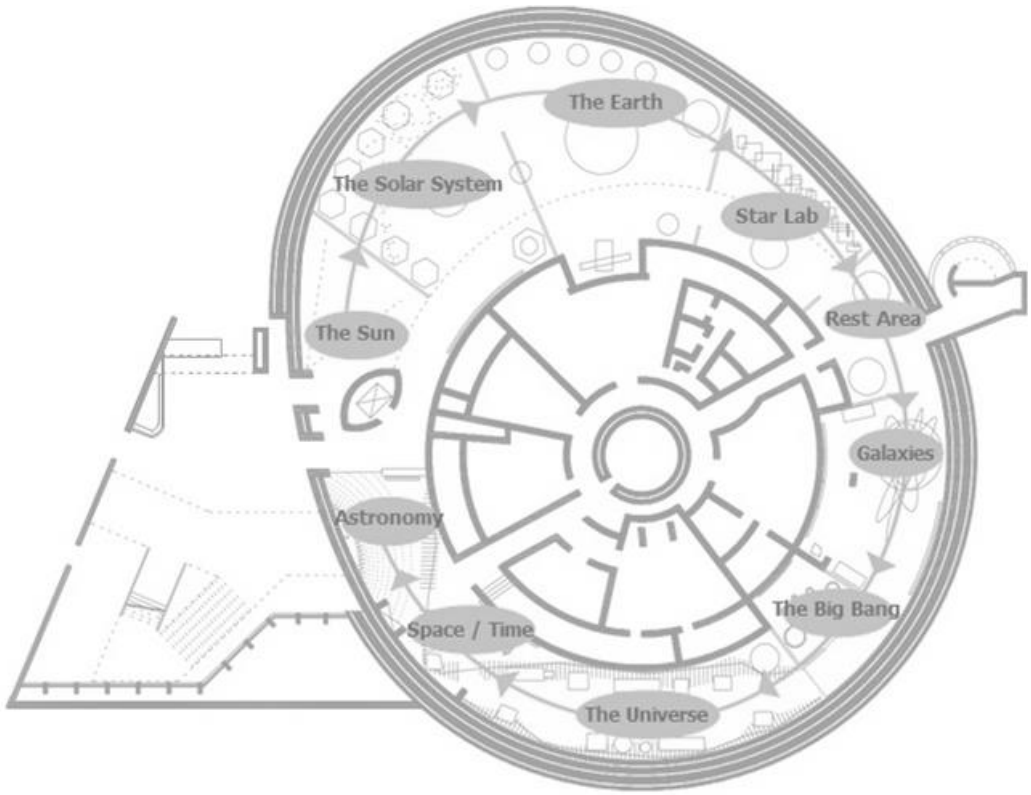


Fig. 8.3.3-1. The storyline of the Cosmos as the narrative plan for the gallery, from Zone 1- the Sun to Zone 10 - Astronomy, please find **Appendix 5.2** - Extended Exhibit Matrix for detailed information.

Source: Based on preliminary design brochure for HKsM, edited by the author.

This proposed concept rewrote the original contents in the gallery, with a reversal of the storyline that begins: not with the beginning of the universe, but with the first star that everyone knows – the Sun, a main sequence star on the outer edge of the Milky Way. The story introduces the Sun and describes its place in the centre of our solar system, allowing the visitor to explore the planets that orbit around it and establishing our own planet's place in the order of things. This is important from an educational perspective, because the numbers and scales involved in an exhibition of the cosmos are truly astronomical, and without a frame of reference quickly become meaningless. The journey for this hall proceeds from the Sun and out through the Solar System, looks out at the constellations and perceives other suns with their own planetary systems. To get a better understanding of those other suns, visitors follow the storyline and find they step into the Star Lab, a laboratory type environment with experiments and demonstrations that explain how astronomers measure and map the skies. Armed with this knowledge the storyline takes them further to marvel at the immense number of galaxies that make up the universe and describe the galaxy in detail. Only at this point, the proposed narrative starts to ask the question: "Where did it all begin?" A presentation theatre describes the birth of the universe and its expansion to the state it is in today. From this theatre, visitors enter the next section of the exhibition which explores what we know of the universe and introduces the proofs and theories behind the Big Bang and looks into the future to predict the end of the universe. The final section of the exhibition looks at the more practical side of Astronomy, from optical telescopes to radio waves and massive computer analysis, encouraging the visitor to get involved in crowd-sourced discovery programmes. With the focus on the role of scientists and engineers as the final message of the gallery, the visitor then continues their journey to the next exhibition galley - the Hall of Space Exploration.

The storyline concept for the Hall of the Cosmos makes use of the existing circular and unidirectional nature of the gallery to relate the evolution of the universe. Visitors will venture into a dimmed and mysterious space with dynamic lighting, wall murals and elaborate decorations. The major themes of the Hall of the Cosmos will be space exploration and the Sun-Earth relationship. The new exhibition space involves numerous of opportunities to use vision, touch and sound in experiencing augmented space. And numerous opportunities to actively engage with the museum providing visitor involved exploration and learning.

This new HKsM experience and identity are built upon the concept that interacting with the 'storyline' is an ongoing journey, not simply a single visit to later reflect upon. Once captivated by the exhibition, either by an initial digital experience or a physical visit to the galleries, it will become an essential part of the lifelong learning and entertainment resources for museum visitors. By creating the visiting experience that seamlessly integrates all the varied ways of AR engagement with the museum, uniquely tailored to walking into the Hall of the Cosmos or accessing resources digitally, the museum becomes everywhere, all the time. Central to this new vision for HKsM is the integration of exhibition zones and digital engagement as a seamless visitor experience. Together they will create a new interactive museum environment that will not be a place, but an experience. This design outline was reviewed and approved by the client in Hong Kong, after the approval, we started to develop the conceptual design work. The museum director, curators and museum designers sat in meetings to discuss and review the designer's concepts. During the detailed design development stage. These were hundreds of inter-disciplinary meetings to communicate all the different parties' opinions. The detailed design development is presented in the next subsection.

8.3.4 Narration for different exhibition zones

Zone 1 - the Sun (Orientation Zone) - Entering the exhibition hall, the visitor is first confronted with a massive projected image of our Sun burning brightly against the black emptiness of space. This exhibition zone acts as the orientation area and a group interactive quiz introduces key concepts of our Sun and Solar System in a fun and exciting way. We are using the quiz format acts as an 'ice-breaker' to get groups into the frame of mind to explore the museum and help them make the transition from the bustle of the city outside and the concepts and ideas that the museum visit will facilitate. The perimeter of the zone and the connecting wall through to the next zone are populated with exhibits relating to the Sun, its relationship to the Earth and introduces basic concepts of solar science. These exhibits lead the visitor on into the Solar System Zone.

Zone 2 - The Solar System - The next zone is dominated by scale models of the planets in the solar system set against a huge back-lit light box graphic image of the Sun (**Figure 8.3.4-1**), which looped 3-minute video of Sun footage, showing turbulent surface and solar flares. The ambience of the zone is bright and clean with hi-tech exhibit counters set out below beautiful scale models. The planets are designed to be suspended overhead and below each is a display counter with a suite of exhibits built in. Each suite of planet exhibits will consist of the following:

a. A 'viewing window' out onto the surface of the planet. This will be a video animation of what the surface will look like.
b. A 1Kg weight on scale balance that the visitor can lift – the weight will be altered to match the gravitational force of each planet, so that the weight on the Venus counter will hardly be lift-able while the one on the Mars counter will lift easily.
c. A computer screen with statistics and data on the planet for detailed information

d. A model of a space suit to illustrate the type of protection a person would need to survive on the planet.

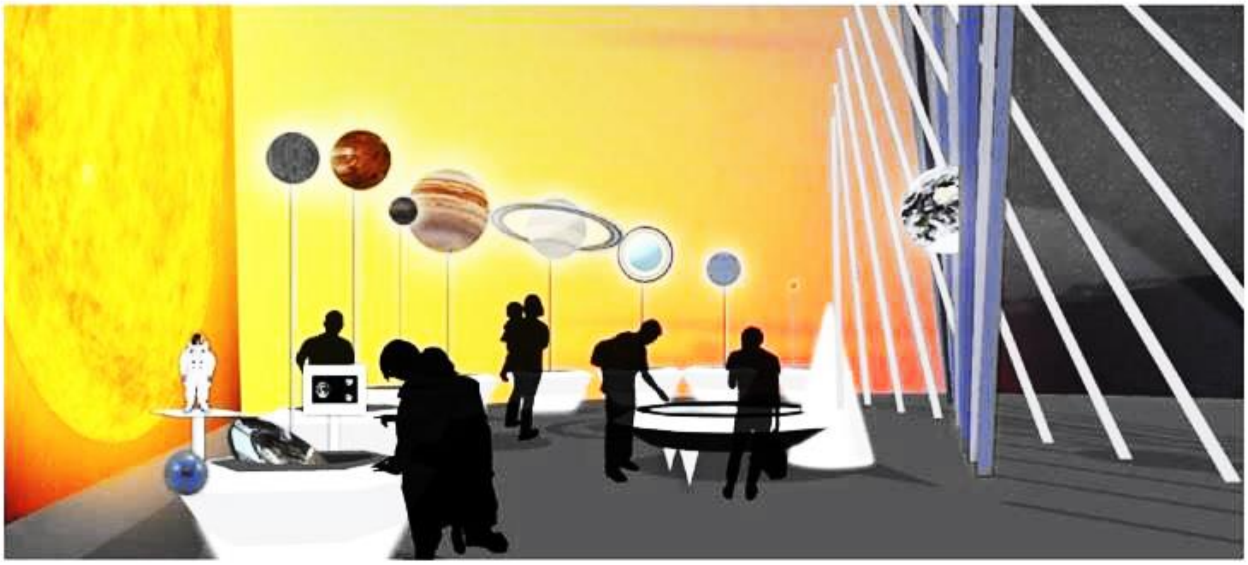


Fig. 8.3.4-1. Concept design for the Solar System zone inside the Hall of the Cosmos, HKsM.

Zone 3 The Earth - The large projected sphere of the Earth links the Solar System zone to the Earth zone (**Figure 8.3.4-2**). Passing below it the visitor sees a majestic Foucault's Pendulum in the centre of the zone, slowly marking off the rotation of the Earth. The pendulum is mounted overhead and the markings are printed on a glass panel, and spatial lights project the shadow onto the floor. The design of the area is more fluid with many hands-on, participatory and interactive exhibits integrated into the spatial structures. Around the walls of the zone, a series of interactive experiments are set out on counters. This area will be dominated by large images of Earth, which is about 3-minute long with a commentary and should focus on what makes Earth special. The sequence of slides is from outside the Earth's atmosphere, down through the atmosphere, down to sea level through the oceans. Slides are chosen for their excellent photography, drama, colourfulness and subjects, as images from the depths of the oceans, and the microscopic worlds of bacteria to remind visitors that the majority of this planet is inaccessible to humans. The screen wall that divides this zone from the next is embedded with points of light that form the constellations and we will use this section to explain how early scientists have used observation and mathematics to deduce the movement of the planets. This allows this space to introduce the stories of some of the great early thinkers such as Newton and Kepler.

Fig. 8.3.4-2. Concept design for the Earth zone inside the Hall of the Cosmos, HKsM.

Zone 4 Star Lab - The next zone has a different design approach: when the visitors steps into the Star Lab, they can experiment with some of the fundamental concepts that are used by astronomers in their understanding of the stars (**Figure 8.3.4-3**). The zone is designed like the interior of a starship from the future, with control desks and equipment embedded into the walls. On the left-hand side, the curved wall houses a number of experiments and glass 'infinity windows' give the impression of looking out into an endless star-field, using motion-sensing technology, visitors gesture and drag the outline constellations to the correct position in the star-field. When they are close, the constellations click into place with a starburst glow to show that they are correct. On the right-hand side, an augmented space based on Stella Evolution shows that stars can be classified according to their life-cycle type. Interactive table top projection of Hertzsprung Russell (HR) diagram with introductory text and typical star life-cycles. And speakers are mounted above the perforated ceiling panel and allow for sound effects. A RFID tagged block which represents our Sun can be moved around on the projected HR diagram. Following the puck as it is moved, there is a small Dialogue box next to it, which shows what our sun would be like (i.e. size and colour) on the part of the HR diagram that the puck has been placed.

Fig. 8.3.4-3. Concept design for the Star Lab zone inside the Hall of the Cosmos, HKsM.

Zone 5 Rest Area - An area adjacent to the rest-rooms will be established as a small library and seating area with play space for young children. A ball pond will be used as a demonstration of estimating numbers for older children, whilst younger children can take time out from the space museum to play. Stylistically the exhibition setting will continue the star ship theme with a futuristic design for seating and interior finishes. From this point on the museum ceiling height is reduced to 3.5 metres, to create a cosy rest and space for visitors.

Zone 6 Galaxies - The visitor enters a darkened zone with a beautiful sculpture of a typical galaxy suspended overhead (**Figure. 8.3.4-4**). The model is made from thousands of glowing fibre optic tips that cluster tightly in the centre and spiral out in arms like our Milky Way. The sculpture is robust enough that visitors can touch it or put their head up inside it, to experience our location in the galaxy and, by looking around it, appreciate its form. Exhibits along the wall of the exhibition zone display the Milky Way and other galaxies to convey the huge number of galaxies that make up the observable universe. For example, the visitor can assemble a diagram of our galaxy with electromagnetic pieces - a series of arcs and shapes that represent what we know of the structure of the Milky Way on table projectors. Clues to the structure from a variety of imaging sources are presented and magnets below the table 'lock' certain shapes into position. When all parts are assembled correctly a projected image of an artist's reconstruction of the Milky Way is projected down over the diagram and model.

In this zone, practical experiments with a spectroscope establish the concepts of spectral colours that stars and galaxies emit as signatures by observing the emissions from Hydrogen and Sodium. Another simple experiment presents the Doppler Effect and explains how, when coupled with the knowledge of spectral signatures we can deduce that galaxies are moving away from us and that the universe is expanding. Those practical experiments coupled with another exhibit that describes our attempts at mapping the Milky Way and why we cannot define the structure of certain areas. A large board with two or three spiral arms as dials allows the visitor to position LED cluster lamps (representing gas clouds) at different positions on the 'arms'; the further out along the arm the lamp is placed in relation to our view point in the centre of the dial the colour is changed to darker red.

Two or more clusters in line will have the same colour (the same Doppler shift) and therefore be indistinguishable for our observer on Earth. In the following augmented space, it shows that astronomical bodies are evenly distributed in the universe no matter how deeply we look into the universe, the same number of stars appear to be present. Two holograms hover in front of the visitor with a series of lights mounted vertically. The higher of the two holograms is at a higher magnification than the lower one. By moving the lever, the visitor can move the two holograms up or down, so that if the movement is upward the lower images become magnified and the upper image disappears. Downward movement results in the previous upper image moving downward and shrinking in size. At the same time as the holographic images move the lights by the side of the images switch on and off to emphasise the movement. In this zone, the visitor will understand that the universe is expanding, and if it is expanding then it must have expanded from somewhere, which leads us on to the next zone.

Fig. 8.3.4-4. Concept design for the Galaxies zone inside the Hall of the Cosmos, HKsM.

Zone 7 The Big Bang - The birth of the universe is presented in a holographic augmented space with an animated presentation that describes the first seconds and minutes of the Universe (**Figure. 8.3.4-5**). The theatre is enclosed with the soundproof wall and anechoic panelling to the interior will deaden the noise inside. This presentation is conceived as an important point in the Hall of the Cosmos that shifts the focus from the observable universe to the theoretical universe which is developed in more detail in the next zone.

Fig. 8.3.4-5. Concept design for the Big Bang presentation inside the Hall of the Cosmos, HKsM.

Zone 8 The Universe - On entering the Universe Zone, the visitors is first confronted with a wall of chaos - A large cylinder is filled with small balls that are in constant motion. The visitor can introduce a larger (static charged) ball into the chaos to observe the smaller balls clustering to it, to represent the formation of gas clouds in the early universe. The walls are set out as straight columns that mark the space and are also a logarithmic timeline of the life of the universe. Between the columns displays and experiments allow the visitor to explore some of the fundamental questions of the universe. To explain the breaking of symmetry that occurred in the early micro seconds of the Universe a striking display of water in all three states – gas, liquid and solid – is recreated in a tank along with models of the molecular structures of Oxygen and Hydrogen. The demonstration of their rotational symmetry when alone and un-combined is compared to their particular shape when they combine as water, and further as ice. At a computer touch table, the visitor can explore the early universe by altering the states of the original mass and energy configurations to understand that the make-up of the universe is so simple – and that this is one of the mysteries at the heart of science. Nearby is a model of the large Hadron Collider with a newsfeed from the LHC and description of the search for the Higgs Boson. The featured augmented space of this exhibition zone is also the feature exhibit of the Exhibition Hall, it is called the Galaxy Surfing Experience, and the design process of this featured augmented space will be detailed in **Chapter 8.4**.

Zone 9 Space / Time - Passing through the warped wall that represents space and time is a small zone devoted to the theories of space and time. There's an augmented space base on the idea of 'Time Machine', which reveals the story of time travel until the death of the Sun. The visitor can drive the machine forward and back from today's time frame. The images are simulated images of what will happen to Hong Kong as eventually the Sun gets hotter and expands to engulf the inner planets and the earth. The frames display some information as the machines move forward and back (e.g. time, temperature, light levels, sea levels and life forms). Apart from that, the surrounding augmented space of this exhibition zone features video displays which highlight three astronauts who are working on the space station, one of the most ambitious international collaborations ever attempted. Each video is a personal journey that complements the space exploration story around it, which serves as an introduction to the Astronomy Zone.

Zone 10 Astronomy - The final exhibition zone brings the visitor back to Earth and explores the technical side of Astronomy today, explaining our efforts to see further and wider with each technical advance. A range of telescopes will line one wall, and computer screens will allow visitors to take part in crowd-sourced astronomy, joining in with comet hunting or surveying the surface of the moon. The emphasis here will be on the scientist and the science of astronomy with a view to encouraging young people to get involved. A wide range of crowd sourced research projects are now accessible on-line and they will be presented in this zone with the potential for the visitor to register and continue their quest home. The concept is to make this space very dynamic with challenges and experiments that change and develop drawing on the visitors. It will be a place where they can feel engaged with the museum and inspired to continue watching the sky at night.

8.3.5 The spatial analysis of the final setting

As the final exhibition setting is presented in **Figure 8.3.5-1**, every single exhibit inside the Hall of the Cosmos is detailed in **Appendix 5.2** - **Detailed Exhibit Matrix,** including the exhibit description and interaction method. As an exhibition designer, the author wants to make sure that exhibition structure allows all those interactive artefacts and their surrounding augmented space to be displayed in setting appropriate for both conversation and learning, thus make exhibition's physical environment enhance the exhibit content. It should viscerally echo the exhibition's messages and themes and be multisensory. A successful physical space is one where a visitor may absorb the general meaning of the exhibition by just moving through the physical space of the gallery, without having to read a single label or touch any interactive exhibit.

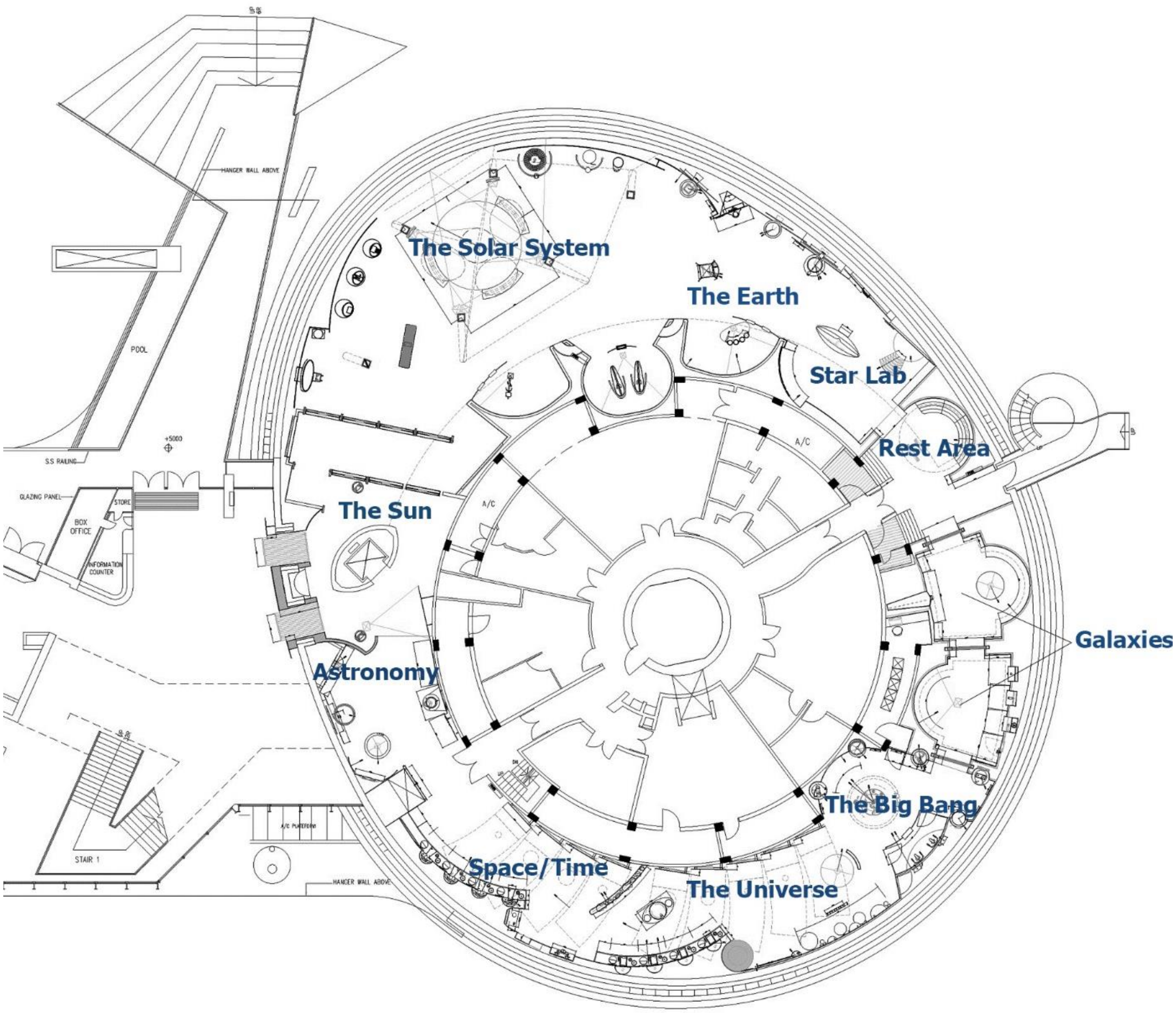


Fig. 8.3.5-1: Final exhibition setting of zones 1-10, the Hall of the Cosmos, Hong Kong Space Museum.

Human movement is frequently described in an abstracted from using its topology. Topological description allows researchers to focus on the structural relationship among units of movement while disregarding the details of phenomena (Kim, H et al., 2008). The author has adopted space syntax analysis inside exhibition settings inside the MAGNA and the THINKTANK, for concerning their overall geometric connectivity of locations and augmented spaces based on spatial links only, in order to capture the easiness or difficulty of movement in its physical environment (Hiller, 1996; Penn et al., 1998). And the author chose to adopt the same method for spatial analysis inside the Hall of the Cosmos, HKsM.

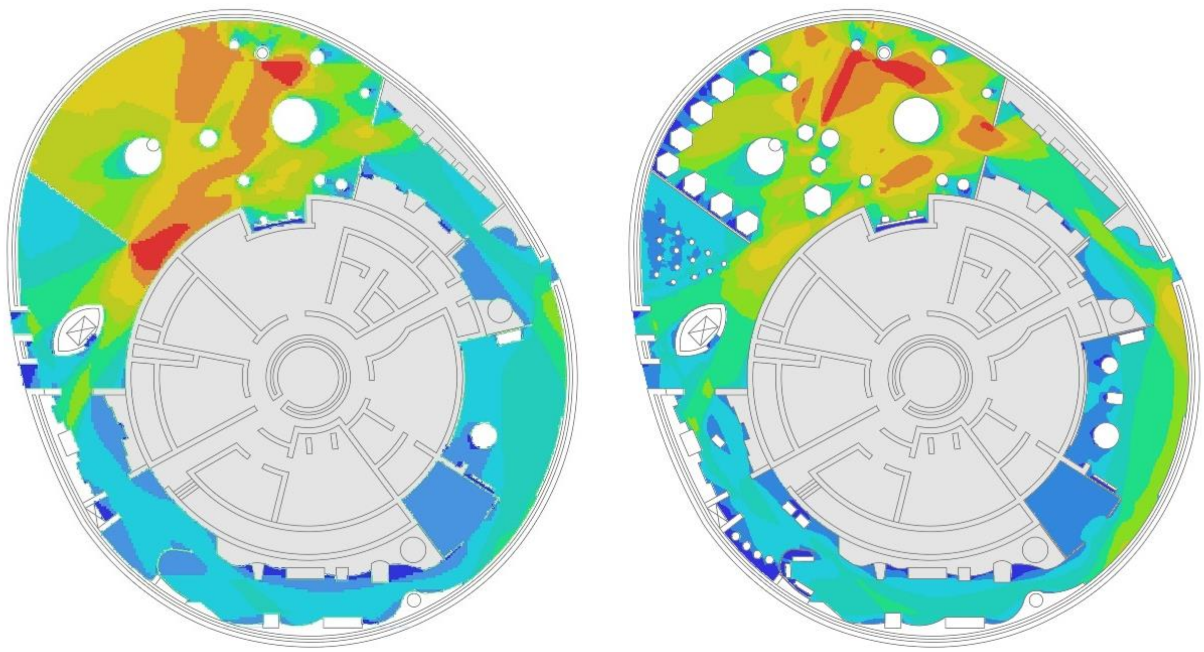


Fig 8.3.5-2 Visibility (Left) and Permeability (Right) through VGA analysis for the Hall of the Cosmos, HKsM.

Through Space Syntax - VGA analysis, as can be seen in the visual integration graph generated at eye level and knee level (**Figure 8.3.5-2**), the most integrated area extend from the introductory zone is the Solar System exhibition zone. While medium level integration values are located at the gateway in the sequence from the Earth to the Big Bang exhibition zone (Northern end to the southern end). The lowest level integrations values are based on those exhibition zones at the bottom of this plan. However, as the author mentioned before, visitors on those highly-integrated augmented spaces are normally impossible to concentrate their attention for a long period of time. On the contrast, exhibition area like the Universe zone which got a low level of visibility and permeability is in fact where the in-depth interaction is produced, they have longer holding power and higher visitor engagement levels.

8.4 Featured Augmented Space Design

The augmented space design for the Galaxy Surfing Experience is located in the Universe zone. The starting point and main aim of the project were to design a playful and engaging learning experience for visitors.

The initial idea of the experiential design relies on discovery and curiosity to be the driving factors of visitors' experience. The experience's mechanics are designed to facilitate in these values.

This part of the DBR connects the process of learning the process of augmented space design; from being a novice in the field of exhibits, towards a more experienced role in designing new augmentation. Elaborating design concepts and ideas plays a key role in the design process. The information gathered during the process of this featured augmented space design results in an increasingly complete picture of the project. Prototyping and materialising ideas and concepts are done throughout the process. On one hand, they help piecing the puzzle, showing understanding of the situation. On the other hand, they offer a way of communicating the designs with other experts and external parties, which helps researching the effects of the design. With the outcomes of this practical experience, research it is possible to formulate more accurate requirements for augmenting space in practice. This means design requirements are formed dynamically throughout the process. With each cycle of research, design and experience it is possible to formulate these requirements more detailed, enabling iterations to be completed with evaluation sessions.

The whole process is conducted through developing, prototyping and evaluating the Galaxy Surfing Experience, and it can be divided into 3 parts:

1) Research & Analysis: through context analysis, design requirements have been formulated to pinpoint conceptual fields of opportunity. Requirements have been formulated from the research performed to ensure the design will meet the standards required for a successful exhibit. Visitor requirements resemble requirement applicable to the target group.

2) Ideation & Concept: with the preparations performed the design process from here on focuses on ideating and conceptualising. 3 concepts/ideations have been tested and verified with the target users through a user involvement session. From these 3 concepts, the final concept formed: The Galaxy Surfer. It is an exhibit that focuses on teaching children different aspect of the solar system by allowing them to physically surf through space, offering an immersive experience that is as fun as it is educative.

3) Fabrication & Implementation: After the concept choice and development, here the embodiment design has been made ready for fabrication, as well as elaborate software design that is required for the exhibit to function. The exhibit has been installed and tested that enables iterations of software design and final evaluation of the concept.

8.4.1 Design requirements analysis

The initial idea of this feature augmented space relies on discovery and curiosity to be the driving factors, and mechanics of the interactive exhibit are designed to facilitate in these values. Although AR in general offers almost limitless possibilities for rules and game elements, there has been opted for a clear and simple formulation of the visitors' goal. Due to the fact that normally visitors only have 3 minutes to experience the exhibit, goals and skills developed by the player, as described in the flow diagram (**Figure 8.4.1-1**) will have to be attainable. Complex game mechanics would hinder this process too much and boredom and anxiety might cause children to stop playing, without being engaged in the learning process.

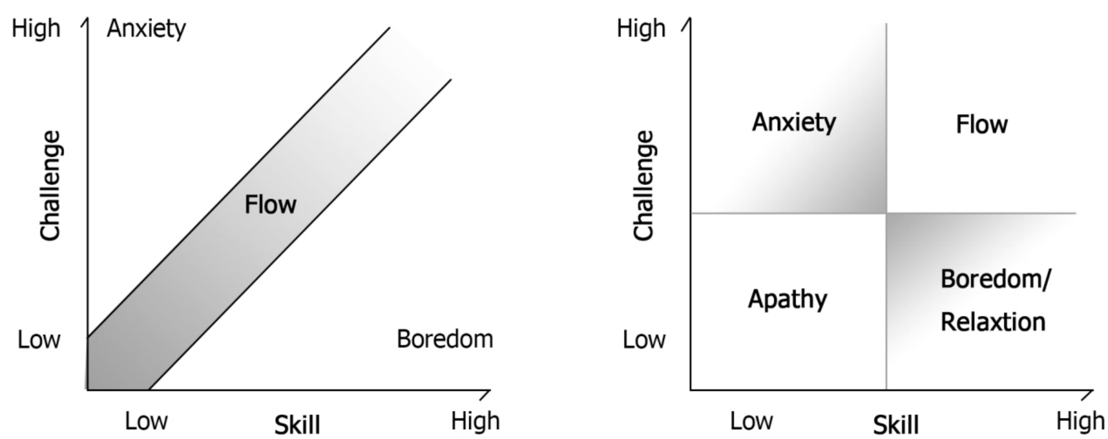


Fig. 8.4.1-1 Original flow model (left-hand side; Csikszentmihalyi, 1975) and reformulated quadrant model Flow (right-hand side; Csikszentmihalyi and Csikszentmihalyi, 1988) taken from (Engeser and Rheinberg, 2008, p.159).

As mentioned in **Chapter 8.3.4**, the focus of the exhibition narrative shifted from the observable Universe to the theoretical Universe from this exhibition zone, which may all be a bit abstract and hard to fathom for museum visitors, especially for the target group of the study - children. With the aim of educating visitors about the theoretical Universe in a fun and exciting way, and letting them be in control of their own experience. This augmented space is designed to facilitate could be seen as a two phased. The initial learning aspect offered to the user is the knowledge "hidden" in the augmented space, ready to be unveiled. This first layer is more obvious than the second layer, which is more subconscious. Constructivism learning objectives are well embedded behind the designed experience. The game world offers an understanding of the Universe by presenting the planets and artefacts in an ideal situation in a "presentable" way, it offers the visitor the information needed to form a mental image of the system of the Universe, which includes:

- Engaging visitors to be excited and in awe of the huge Universe we current live in
- Teaching basic concepts of spatial measurement and distance
- Encouraging children to explore the universe on their own
- Strengthening visitor's knowledge of planets in the Universe

Combining Design Sensitives generated from case studies, which includes:

- Accommodating different user groups and people of all ages, appeals to children and adults alike
- Leading the process of discovery for children and to encourage them to communicate their findings to their companions
- Supporting the group visit experience
- Providing unique and attractive visual interfaces and layers of interactivity

Apart from those pinpoints above, there are also some external requirements from HKsM, which includes durability and adaptability. The final formulated requirements, as shown in **Table 8.4.1-1**, which evolved from initial discoveries into more detailed product oriented guides. This table will further help to evaluate and reflect upon proposed concepts for the featured augmented space. During the Ideation phase, that took place simultaneously, decisions have been made according to the design requirements as known at these points.

1. Visitor Requirements	2. Design and Development Requirements	3. HKsM Requirements
1.1 Active Experience	2.1 AR Technologies	3.1 Visitor Pass-through
Initial Attractiveness	*Layers of interactivity*	*Participants*
Flow	*Attractive visual effects*	*Interaction time*
1.2 Engaged Learning	2.2 Mechanical Development	3.2 Maintenance
Challenge	2.3 Interaction Design Development	*Durability*
Choice and Variety	*Group interaction*	*Tidiness*
Novelty and Authenticity	*Adequate affordances*	3.3 Educational Value
1.3 Playful Physicality	*Attractive and clear interface*	3.4 Adaptability

Table 8.4.1-1. The formulated requirements for developing concepts of the featured augmented space.

8.4.2 Idealisations and idea selection

Ideation has been the driving force in designing this feature augmented space, and the author proposed 3 idealisations- Moon Lander, Orbit Games and Galaxy Boarders. Researching through design in combination with frameworks derived from **Chapter 5.4** has ensured initially discussable, visual and experiencing results during the process. This chapter discusses the selection and evolution of the augmented space design, from initial ideas, through more detailed concepts towards a final design.

Idea 1: Moon Lander

In the end of **Chapter 4.4.3**, the author mentioned many researchers adopt projection technology to extend the interface of standard desktop applications into physical museum environments, aiming at visitor-entered related interaction. As Mitasova et al. (2016) worked on real-time landscape model interaction using a tangible geospatial modelling environment, which aimed to achieve a more intuitive collaborative interaction with digital museum landscape data, which also might be useful for educational purposes and learning simulations and geological studies.

Based on above research, the first idea is driven by Microsoft, this Kinect driven concept relies on depth measurement from the Kinect sensor to transform a simple sand box into an interactive playfield. Visitors are able to customise their own Moon Lander and learn about distant missions and the problems these rovers will run into. It is initially set to provide 6 individual players with the ability to play against each other, trying to collect as much "soil treasures" as they could. This meant choosing an appropriate moon lander layout followed by discovering the surface of the planet by digging your way through the sand. The terrain would influence the rovers' behaviour, for instance large rovers could not run uphill, and propulsion systems chosen would influence speed. However, the initial idea soon proved to be too expensive providing for 6 players. Also concerns regarding the sand becoming messy in such a competitive approach were raised. Due to this notion, a more co-operative approach was chosen in the second version of this idea. Players would co-operate finding treasures, after selecting the best rover from 3 different variations. The screens were replaced by a central radar indicator showing players possible directions for treasures. By setting out a route towards these goals, a new gameplay dimension was added. The prospect this idea delivered has made it to an idea that has been developed into a form that could be tested with end users.

Idea 2: Orbit Games

The orbit game idea was initially conceived with an image is projected onto a mirror and a receiving plane, enabling the merging of the real and the projected. It enables for a model of the Galaxy to be merged with projected images. This idea engages in that notion. The visitor engages in a game that focuses on orbit dynamics. The user learns about gravity and planet rotations by shooting debris through the Galaxy without hitting any planets, but bringing the comet into an orbit as long as possible. This idea probably has had the longest evolution from idea into tested concept. Initially aiming at creating a tangible system of the galaxy with a gaming element, it grew into a more concrete concept. The current day attention for the International Space Station (ISS) and the problems with space debris around earth made a trending topic for this concept. In the evolution of the idea this topic was changed; not the entire Galaxy, but planet earth itself became the centre of the exhibit, with space debris floating around. In the last stage of development, the ISS would have to be protected from space debris, without damaging the ISS or hitting earth with meteors.

Idea 3: Galaxy Boarders

The galaxy boarders' idea picked up where the game floor was not informative enough and offered too shallow interactions. The direction this idea focuses on is creating an immersive, playful experience for visitors in which they are able to learn things by doing. The immersive experience galaxy boarders' offers is for visitors to emerge themselves in the galaxy racing their way through, collecting information on different aspects of the Universe, whilst enjoying the beauty of the surroundings.

With these three feasible concepts in development after ideations, a user involvement session was planned, built up and tested with the help from Exhibit Technologies – Mr. Paul Mumby and Digital Curators – Mrs. Zara McKenzie in the design team during June 2015 inside HKD studio in UK. The aim of the session has been to evaluate the design vision and compare the concepts on equal grounds.

The rapid prototyping method used, varied in functionality and all three where by no means finished products. Two of the concepts, the Galaxy Boarders and the Orbit Games, rely on screen based interactions, whereas the Moon Lander concept differentiates itself by offering a more tangible form of interaction, as shown in **Figure 8.4.2-1**. These 3 prototypes were set-up for 20 participants[27] in total to experience, per four participants 45 minutes were scheduled, which was 10 minutes of play per exhibit prototype and a 15-minute discussion round of recommendations from the participants. An important part of this session has been to introduce participants to the storyline of the concepts, to achieve the right mindset. Participants were not asked to answer question, but deliberately told their help was needed to improve the designs and to contribute to the design through a co-design session.

The experience of the prototypes would trigger participants to think about the designs and come up with additions and tips to improve the design. Detailed descriptions of three prototypes setups can be found in the following words.

[27] All participants were selected on apparent age to fit the initial target group ranging from 6 to 18 years old.

Fig. 8.4.2-1. Left: Participating children playing the moon lander game; Middle: Participants protecting the International Space Station from space debris; Right: A participant surfing through the solar system.

Source: Photographed by the author.

Elevation of the Moon Lander

The first concept tested was the Moon Lander concept. The prototype is built around a sand box. A beamer is projecting an image on the sand, creating a dynamically coloured landscape. The dynamics of the game an achieved through a laptop running Photoshop with a multiple layer setup. Digging the sand affects the colour projected. This is done manually using these pre-setup layers. The game mechanics this concept relies upon were implemented to an extent they could be experience by the participants. Through a wizard of Oz[28] method treasures were revealed to the participants, followed by the children having to drive a small toys car towards these treasures to collect them after locating them using a static radar image. The wizard of Oz method poses some limitations to the working of this prototype. Whilst unveiling new treasure objectives was not limiting, real-time colorization of the environment took some practice. More of a challenge opposed the "refereeing" of the participants to follow the rules of game dynamics. The method used here allowed for the participants to experience the essence of the concept, exploring the challenges mars explorers face when sending out autonomous robots towards far away planets.

[28] In the field of human–computer interaction, a Wizard of Oz experiment is a research experiment in which subjects interact with a computer system that subjects believe to be autonomous, but which is actually being operated or partially operated by an unseen human being.

One of the first noticeable characterisations of this concept was the fact that visitors especially kids in our experiment, love to play with sand. Even though the workings of the exhibit were limited, creativity of the children was very much stimulated in this set up. A state of flow was very soon reached, and after the assignments were done, participants were soon taking over controls and started creating their own rules. They took over the controlling laptop and started painting their own landscapes whilst debating new rules and challenges. It was clearly noticeable this exhibit setup was very intriguing and fun to play with. 20 minutes of play was clearly not enough. A very noticeable fact as well was that this exhibit produced a lot of mess. Sand was spread around the room, and the floor surrounding the exhibit became covered in sand as well.

Evaluation of Orbit Games

The set up made for trying out game mechanics was using a hacked Nintendo Wii-Mote[29] for aiming. The software made functioned to a degree that visually it was very appealing and defending the ISS from space debris really stood out. The software was set up to be in a stationary position, with a view from across the ISS. Children were to spot harmful space debris and eliminate it using a laser system. Orbit Games concept relies on the possibilities for hardware development with a real model of the ISS in front of a projected image. This prototype did not have the real-life model standing out in front, but it was included prominently in the software game. Also, no animated space debris was in the game although spectacular explosions were added when the ISS was successfully defended. Although the prototype was working, aiming with the Wii-Mote proved to be too difficult for children. It required fine motoric skills not yet developed at their age. After a short period of trying out, the test was continued using the mouse.

From the start of the game, children were incredibly enthusiastic about the ISS and the looks of the game. After this initial awe, immediately noticeable was the recognizable functionality of the exhibit. Children this age have a broad reference of video games and started shooting space debris right from the start. Some

[29] The Wii-Mote is the primary controller for Nintendo's Wii console. A main feature is its motion sensing capability, which allows the user to interact with and manipulate items on screen via gesture recognition and pointing through the use of accelerometer and optical sensor technology.

of the debris was hard to discover, and this triggered children to start working together to discover. For a short time, this game was very fun to play, and got the children aroused. It triggered enthusiasm, but there seemed to be no interest in the underlying learning experience of space debris being harmful and how to cope with this danger. There is too much focus on action for a learning experience in this set up.

Evaluation of the Galaxy Boarder

The prototype of the Galaxy Boarders was set up using a Wii-Balance board[30] to control the experience. The hardware was programmed to operate a game projected to a screen in front of the participants. The game represents the Galaxy, which was modelled and using a game engine. The experience of flying through the Galaxy was simulated. This combination of the Galaxy and the balance board controller made up a glimpse of what the final concept could look like. From starting the experience, the only instruction was given to fly to the Sun, this to initiate movement and make intentions clear.

One of the first limitations in this prototype was the universe to explore; only our own solar system was modelled in the software. The sizes of planets were correct, but for time purposes the distance between planets was shortened, also, a lot of concessions to reality were made. No true 3D movement was possible as would be expected in space; the participants were only able to make planar movements. Moreover, this concept relies on information to be gathered in the Universe. These gameplay elements were not included in the software, nor were there assignments or collectibles to be gathered. These instructions and information was given orally during the experience. Right after the start a noticeable flow experience was reached. The combination of steering the game character through space using the balance board and the visual representation of something ungraspable as the Universe triggered curiosity. The active interaction needed to surf through the Galaxy proved to be challenging but rewarding. For some children though, mostly smaller children were experiencing some difficulties controlling the game. The software running to control the game was not flexible regarding body weight, which resulted in lighter children having more difficulties to steer than heavier children. Triggered by curiosity, questions arose about the universe, planets

[30] The Wii Balance Board is a balance board accessory for the Wii and Wii U video game consoles

and our solar system. Children loved discovering parts of the solar system they found appealing and started wondering about facts hidden in space. The freedom to explore triggered a learning experience.

	Moon Lander	**Orbit Games**	**Galaxy Boarders**
Visitor Requirements			
1.1 Active Experience			
Initial Attractiveness	2	1	2
Flow	2	1	2
1.2 Engaged Learning			
Challenge	-1	2	2
Choice and Variety	1	-1	2
Novelty and Authenticity	2	-1	1
1.3 Playful Physicality	2	1	2
Sub-score	8	3	11
Design and Development Requirements			
2.1 AR Technologies			
Layers of interactivity	-1	-1	2
Attractive visual effects	2	1	2
2.2 Mechanical Development	2	2	2
2.3 Interaction Design Development			
Group interaction	2	1	2
Adequate affordances	1	1	2
Attractive and clear interface	2	2	1
Sub-score	8	6	11
HKsM Requirements			
3.1 Visitor Pass-through			
Participants	2	-1	2
Interaction time	-2	2	2
3.2 Maintenance			
Durability	2	1	1
Tidiness	-2	2	1
3.3 Educational Value	1	-2	2
3.4 Adaptability	1	-1	2

Sub-score	2	1	10
Total Score	**18**	**10**	**31**

Fig. 8.4.2-1 Elevations of these three ideas, score from -2 (Not at all likely) to 2 (extremely likely).

The first idealisation - Moon Lander kept children focused for a long time, however, it is bit too long for a science exhibition environment. The sand this exhibit spoils is an issue to consider. The most valuable asset this concept has to offer is its opportunity for open ended play. It shows that freedom of choice and novelty are of value in an exhibit. Learning activities where more limited in this concept and should be focused on when this design was to be continued. The second idealisation about International Space Station (ISS) is a trending topic at the time this project taking place. It is an opportunity to attract people. This set up however did not engage visitors beyond that point and did not trigger the imagination enough for engagement to appear. It barely offered an added value to shooting games children are able to play at home. On the practical side, in controlling games fine motoric skills are something to take into account when purely designing for children. The third idealisation - Galaxy Boarders concept seems to be the right mixture of fun and learning, and offers the possibility to provide visitors of a science centre to provide information in context. Regarding interaction there is a challenge to provide the same level of control for children of all ages and body weights. Furthermore, based on Design Sensitivities, it appeals to children and adults alike, leads the process of discovery experience and provides unique and attractive visual interfaces and multiple layers of interactivity. This idealisation was selected as the final concept for the feature augmented space design.

8.4.3 Interaction and interface design

As mentioned in the last Chapter, to initiate curiosity, the goal of the Galaxy Surfing Experience presented to the visitors as following: 1) help the surfer to discover the complexity of the Universe, 2) collect information about different Galaxies, by flying through clearly identifiable “targets” that present them information about the Universe, these targets are presented as tokens. Players of the game have 3 minutes in total to complete the goal of gathering as many points as possible. The program flow of the game is shown as **Figure 8.4.3-1.**

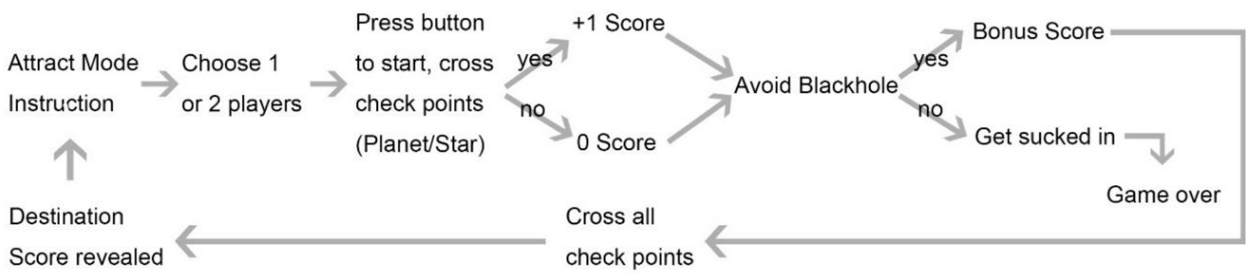


Fig. 8.4.3-1. Program Flow of the Galaxy Surfing Experience

The solar system, by nature, is a place of contrasting lighting circumstances. The sun lights up the visible areas brightly, however, since in space there is nothing for the light to reflect upon, indirect light is non-existing. Shadow sides are there for pitch-black. This poses some difficulties for the game. Some players in the initial user involvement session indicated that they were having trouble following the character in darker areas. To solve these visibility issues the game character was designed to have glowing lights on its backpack and space suit, which representing the tokens he is after. This would subtly indicate a connection to the curious signs and the storyline. The Galaxy Surfing has to collect information in the solar system by flying through the signs.

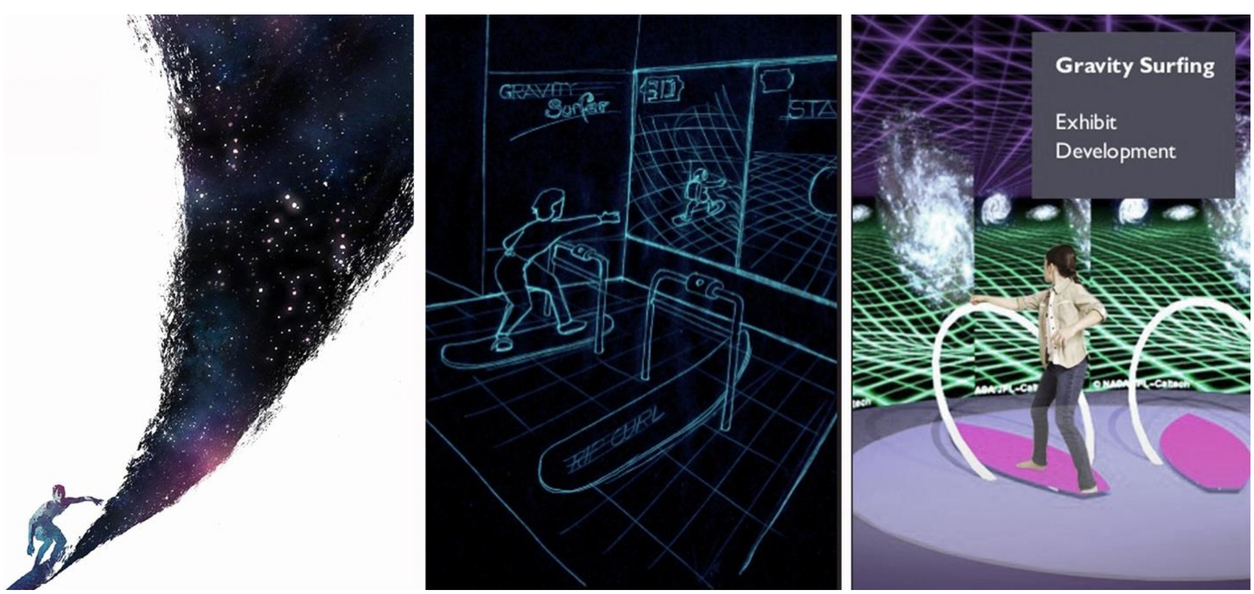


Fig. 8.4.3-2 Left: The concept image of the Galaxy Surfing Experience; **Middle:** The hand-drawing of the Galaxy Surfing Experience; **Right:** The primary design of the augmented space.

Source: Illustrated by the author.

User interface design

The user interface, through design and iteration has been kept as simple as possible (**Figure 8.4.3-2**). From the initial attraction onwards, the player's actions have been deliberately designed. This sequence starts when the visitors walks up to the exhibit. An attractor screen shows the universe bristles with the structure on all scales. When the visitor steps on the controller, the game is initiated. A "warp" effect and bang land the player into the Universe, displaying a welcome message and the goal to obtain as much blue information tokens / game checkpoint (see **Appendix 5.6** for details) as possible. From here on the player is free to move wherever he or she desires. The only visible display aspects, after several iterations, are the score counter and mission statement. Initial versions of the game left room for confusion about the goal of the game since the only visible aspect was the score counter. The analysis has shown that one of the factors influencing flow and engagement is the possibility for players to affiliate themselves with the game's character. Children involved in the initial user studies indicated that a different game character would be appreciated.

Fig. 8.4.3-3 The interface design for the Galaxy Surfing experience.

Source: Illustrated by the author.

In order to not influence the player's flow or attention, the Head-Up Display (HUD) has been designed to be as minimised as possible, the required information is animated into the play screen when applicable. When the player surfs through information tokens, side panels slide in from the side, enabling overlay text to appear whilst still being readable. These information panels are displayed left and right, providing places for two languages – English and Chinese to be displayed at the same time (**Figure 8.4.3-3**). In the centre of the screen, an image is shown elaborating the information given through text. Since this picture is displayed in front of the character, it appears for a shorter amount of time than the text on the side. In this way, the screen is clear for navigation.

8.4.4 Technological approach with AR features

As the author has discussed in **Chapter 3.3**, there are four fundamental components of constructing an augmented space, which are Display System; Sensing, Tracking and Registration; Input and interaction techniques and Virtual content creation and rendering process. For creating the Galaxy Surfing Experience, the author also considered these four components:

Display devices convey computer-generated information to users. For creating the much sought after immersive experience, there was chosen for a projected image rather than screens. Screens would be too costly and have edges running along separation lines. With modern day LED beaming technology increasing in light effectiveness there was chosen to use such a LED beamer. This would ensure minimum maintenance and minimise long-run costs of changing beamer lights. With the visitor ideally standing as close to the screen as possible, without becoming uncomfortable and losing overview, the beamer's source would be at a short distance away from the screen. Here for there was chosen for a short throw beamer. This would ensure a maximum size projection with minimum distance needed. Since the immersion would be greatest with a large field of view covered, and the beamer would only cover the frontal view, a graphic solution was decided upon to cover aspects of the exhibit visible from the visitor's point of view. The ground floor and side panels will be covered with a large print, which represents stars. In the meantime, recessed kick platform lightings (as shown in Figure **8.4.4-2**) are embedded within the physical form to enhance realistic response in an immersive augmented reality environment.

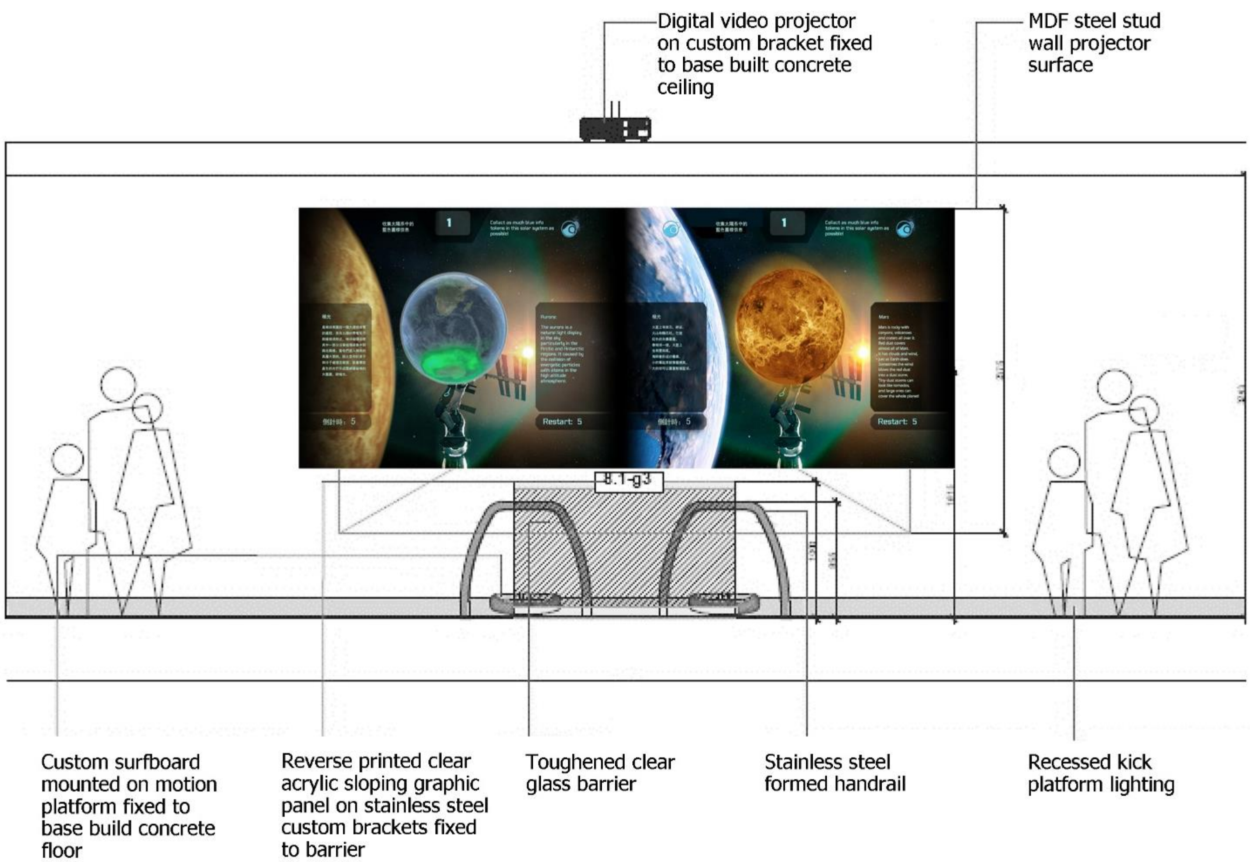


Fig. 8.4.4-1 Construction details for the Galaxy Surfing Experience, the elevation of the augmented space.

Source: Illustrated by the author.

Early user involvement has made it evident that controlling the exhibit would play a key role in the experience of the exhibit. Designing the controller hardware and software working would be crucial for obtaining a user experience that would not be obstructed by hindrance of the controller. With regard to maintenance moving parts will have to be kept to a minimum. Here for is chosen to work with pressure sensors. These sensors do not contain moving parts and are delivered in durable steel casings, and able to endure 250 kg safely without malfunctioning at the same time. The aim of the sensors is to be able to control the game. The easiest way for the controller to work would be through the Human Interface Devices (HID) protocol. HID, such as mice and keyboards, are directly recognised by the operating system, and will show similar behaviour on all PC's the devices are connected to.

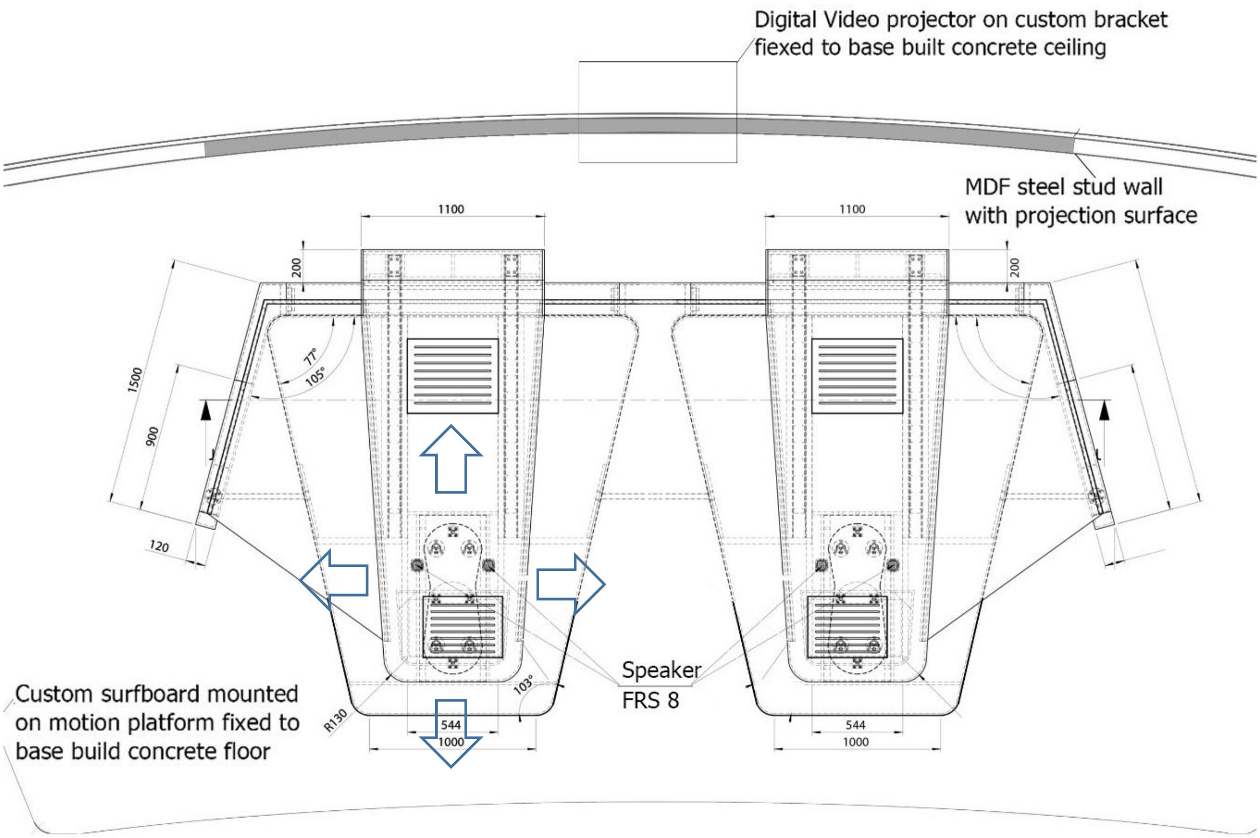


Fig. 8.4.4-2 Construction details for the Galaxy Surfing Experience, the demolition plan of the augmented space.

Source: Illustrated by the author.

The exhibit in the featured augmented space is controlled through a game surf controller, enabling for steering motions in 4 directions. Initially designed for up and down movement next to left and right movement, it seemed too difficult to steer for especially younger parts of the target group. It poses a problem in both obtaining the points as well as finding directions within this feature augmented space. Due to these troubles, this function has been erased, and players can only steer the character left or right. This proves enough for this exhibit, since a lot of the exhibits' behaviour relies on location-based interaction. This means, for instance, that to enter warp speed the player moves towards the outer planets, and it will initiate automatically.

Fig. 8.4.4-3 Left: The sensors mounted on the controller board. The grey box contains the amplification circuitry unit that connects to a pc through a USB. **Middle:** The exhibit during fabrication; the first time the embodiment design becomes reality, after assembly, it is ready for disassembly and painting. **Right:** The first participant of the evaluation session, after the construction phase.

8.4.5 The final evaluation

After several software iterations performed after the prototype installation of the exhibit, a final user evaluation session was performed to gain insights in the project's succeeding resulting in recommendations for future improvements before the installing inside the Hall of the Cosmos, HKsM. This in combination with observations and informal interview about this augmented space design and their visiting experience of the Galaxy Surfing experience. This final setting has been realised and was tested with a 3rd version of the games' software inside HKD Studio. This meant that initial problems for the greater part have been filtered out. Initially visitors are left to experience the exhibit, afterwards asking their permission to ask some questions. A session leader is taking notes and writing down findings, whilst an informal interviewer is asking questions to the participants.

In total 20 participants contributed to the final evaluation session, as the first phase - rapid prototyping study, they were selected on apparent age to fit the initial target group ranging from 6 to 18 years old. To determine the effect of the exhibit an evaluative form was filled out, as shown in **Table 8.4.5-1**. A combination of questions and observations should provide insights in Experience and Learning, which in the flowing four objectives:

1) To determine the overall difficulty of the Galaxy Surfing, children participating were asked for their age, their final scores were also noted. Observation also helped determine possible difficulties.
2) Through observation is determined whether the participant completed the 3-minute game session. If the participant did not complete the session, they were asked for their reason for quitting the game.
3) To find out whether participants have learned something about the Universe, the question was asked: ‘Did you learn something?’, and ‘what you have thought?’
4) The level of attraction of this augmented space is determined by observation, based on whether it lived up to the expectation of the visitor there was asked whether they had fun playing the exhibit.

Data Analysis

In total, 15 out of 20 interviewees were boys and 5 interviewees were girls. The youngest participant was 5 years of age the oldest was 15 years of age. 1 of the girls did not finish, against 4 of the boys. The boys that did not finish were all too light for the gaming board to function correctly. The girl that did not finish also had troubles using the controller. Kids who able to play generally like it very much and they were eager to replay the game when they get the hang of it. All participants that were able to control the board finished the 3 minutes set for the game to last. Older children especially pointed out that they really like the graphics and looks of the game.

Difficulty - Children that are small and light have a hard time steering the solar surfer. They stop playing more often because they are not able to engage in the game easily. Concentration or patience is lost and the game is quit. This seems to be the most common reason to “quit” the game: the inability to control the game as people would like to. A lot of children did not place their feet in the right position. The most common “mistake” is placing the front foot facing the screen, with the rear foot in the correct position. Some children place their feet on the border of the controller in such a way not all their weight is read by the sensors. 5 of the children that did finish the game indicated that they had a hard time steering. They had to get used to the way of steering.

Flow - Flow seems to be highly related to the understanding of the goals and the amount of control people have. With both criteria met, the participants finished the 3-minute session. If one of the 2 criteria is not met, a state of flow will hardly be reached. In the 5 occurrences of children quitting the game, the first encountered difficulty was the controller not reading their weight. This immediately poses problems and kids are distracted by their parents telling them how to act. The game no longer is their own experience and after a short while they quit, without really having experienced the essence of the game.

Learning - Learning did not take place for the participants that quit the game. Of the remaining 15 participants, 3 participants indicated they did not learn anything new, because they knew a lot already. The 12 remaining participants all indicated they had learned something new, of which 8 did not know exactly what they had learned. The remaining 4 participants answered they had remembered one of the information points they had collected earlier in the game.

Attraction - This factor might be the hardest part to influence at this stage of the design process. Luckily visitors are very much attracted to the exhibit. During the time of evaluation session, a queue formed quickly when people were playing. We also found that this constructed augmented space is very popular among visitors of all ages.

From evaluating early versions of the Galaxy Surfing experience in **subsection 8.4.2 – idealisations and idea selection**, it has appeared that in general there were 2 main difficulties in preventing users from reaching a state of flow and engage in learning. The first one is the controlling difficulty; the second is the understanding of the game and how to act. In the final elevation, these issues have largely been taken care off. The level at which the exhibit now operates it offers a good experience for all children older than 7, and controls are hard for younger children that weigh less than 14 Kg. This is the tipping point at which the sensors do not pick up the weight correctly. This causes the children to lose interest in the game and therefor quit. However, the augmented space encourages their parents to step up and play with their children (it is able to endure less than 250 kg safely), as mention in **Chapter 5.2.3**, the facilitating parent can easily spot the knowledge level of their children, guide the visit and to support their children's learning and enjoyment.

In summary, 15 out of 20 participants who did not quit the game, understood well that they had to collect blue tokens for game checkpoints, whether by themselves or bystanders pointed out the mission. This is a big improvement from the initial version and is now at an acceptable, playable level. A state of flow is reached quite noticeably, despite some people having a hard time learning to control the surfing panel. With all those requirements reviewed in the following table:

VISITOR REQUIREMENT		
1.1 Active Experience		
Initial Attractiveness	Initial use should be apparent and inviting. **Requirement met**; with several iterations focusing on improving this behaviour, the exhibit is clear to visitors what to use.	✓
Flow	Visitors should experience flow during the experience. **Requirement met**; when engaged in the experience all visitors fulfil the 3 minutes of play.	✓
1.2 Engaged Learning		
Challenge	The challenges faced by the visitor must be appropriate for the skill level of the visitor. **Requirement partially met**; visitors do face difficulty controlling the exhibit, although most visitors are able to control the exhibit.	▭
Choice and Variety	Visitors should be in control of their experience. **Requirement met**; visitors are free to choose what to explore in the solar system.	✓
Novelty and Authenticity	New augmented space will serve as an egocentric subjective environment, embed with sensorimotor explorations and learning activities. **Requirement met**; This augmented space provide contextual model of learning and constructivism approach to its visitors.	✓
1.3 Playful Physicality		
Interface	Interactions should make use of a Tangible or Physical User Interface.	✓

	Requirement met; the surf controller requires the whole body to find balance and control the game's character.	
Space	It should exploit the existing space in the science museum, and the new augmented space provides innovative ideas and fun activities for its users. **Requirement met**; It provides the ability to transport their visitor into a surfing space in ways unmatched by any previous exhibit.	✓
INTERNAL REQUIREMENTS		
2.1 AR Technologies		✓
2.2 Mechanical Development		✓
2.3 Interactive Development		✓
2.4 Logistics		✓
EXTERNAL REQUIREMENTS		
3.1 Visitor Pass-through		
Participants	The augmented space should preferably support more than one participant. **Requirement met**; the exhibit is two-person experience, and parents are able to participate with their children.	✓
Time	The time spent at the exhibit should be somewhere from 3 to 10 minutes. **Requirement met**; this requirement was adjusted to 3 minutes per session, which is met.	✓
3.2 Maintenance		
Durability	The proposed augmented space design should be durable using wear resistant materials. **Requirement met**; durable materials have been used on the complete exhibit.	✓
Tidiness	The game should not produce a mess. **Requirement met**; No mess is produced.	✓
3.3 Educational Value	The educational value is a key aspect, and has to be present as a central aspect in the design. **Requirement met**; education is the central aspect of the exhibit.	✓
3.4 Adaptability	The content should be easily adapted, and new knowledge could be added with the development of technology. **Requirement met**; content of the exhibit is adaptable, as well as the time per session. Besides that, colours and materials of the hardware can also be altered.	✓

Table. 8.4.5-1. The final evaluation of the feature augmented space design.

With almost every requirement met in the final evaluation, this assignment to develop, prototype and evaluate this feature augmented space has been fulfilled. The educational value of the exhibit is shown by the fact that people pick up bits of information offered to them by the game rapidly, but further study will have to be made to gain insights in deeper learning and understanding of this featured augmented space inside HKsM after years of closures and construction.

8.5 The Summary of the DBR

From an early start, this design-based research project has known as a very pragmatic approach, the author has been focused on making a novel experience but keeping it realistic and feasible for practical aspects of scientific exhibition design.

The first part of the research delivered a detail internal analysis of the Hong Kong Space Museum (HKsM). The content and messages about aerospace technology in the early years of this museum focused largely on a progress narrative, detailing the significant developments and advances of aviation and spaceflight technology. The new mission is to commemorate, educate, and inspire with more advanced technologies, especially with augmented reality. As the exhibition designer, the author needs to cast the subject in an interpretive framework that does not strip it of its power to excite and inspire, based on genuine achievements. Rather, the design team must create a framework that uses these stories of aviation and human beings' achievement in space exploration as building blocks to tell a deeper, more nuanced understanding of the development of astronomy technology and its meaning for our world. For the following exhibition narrative development, it seeks to chart a path for delivering the messages of the modern approach to space exploration, while preserving the inspirational elements of our mission.

As the exhibition designer, the author calculates that the theme of the exhibition should be transmitted narratively. This will allow a smooth flow from one exhibition zone to another and will support the visitor's comprehension of the purpose of the exhibition (Chapter 8.3 – Exhibition narrative development). It is advisable to decide on a storyline for the exhibition form the start of the planning. In that way, it is possible to select the best suiting themes and to design meaningful augmented spaces. In case the storyline has to be created after certain decisions on topics and subtopics have already been made, it should be tried to link the different topics in a way that the connection is easy to understand and to follow. The second part of the chapter followed with those guiding principles and content goals, and the proposed concept rewrote the original contents in the gallery, with a reversal of the storyline that begins: not with the beginning of the universe, but with the first star that everyone knows – the Sun. This exhibition narrative introduces the Sun and describes its place in the centre of our solar system, allowing the visitor to explore the planets that orbit around it and establishing our own planet's place in the order of things. Through the new narrative, the design team wants to present a narrative of space exploration that is intrinsically exciting, informative, inspirational, even moving at times. We also want to infuse that narrative with different themes, ideas, and questions that lead our audiences to be reflective, contemplative, probing, and inquisitive about the period of history when humans gained their wings and first ventured beyond the atmosphere of Earth.

In the last part of this DBR, the approach led to the design proposal being realised into a prototype of featured augmented space design, which offered a clear step by step plan of deliverables and evaluation moments and in this way the process made sure all those design sensitivities were taken into account from an early start. Based on project requirements, the design team generated the primary design with 3 feasible concepts in development after ideation and initial selections, a user involvement session was planned to evaluate the design vision and compare the concepts on equal grounds. After the elevation, we found the third idealisation seems to be the right mixture of fun and learning, and offers the possibility to provide information in the augmentation context. Furthermore, based on Design Sensitivities, it appeals to children and adults alike, leads the process of discovery experience and provides unique and attractive visual interfaces and multiple layers of interactivity. This idealisation was selected as the final concept for the feature augmented space design. With the concept set, spatial AR embodiment has started, it described every design decisions made in this process and how the final design took shape. Last but not the least, a final user evaluation session was performed to gain insights from potential museum visitors to gain insights in the projects' succeeding resulting in recommendations for future improvements.

Realising a design from drawing to real world augmented space has been an experience that was as demanding as it was rewarding. Being exhibition designer, project coordinator and user interface developer at once is sometimes daunting but the support and trust of HKD studio and HKsM made this a challenge that was carried with much enthusiasm and a far-reaching result for this DBR project.

Chapter 9.

Conclusion and Reflection

Figure: Russell, Vincent. (2017). Photograph. Curated Digital Narrative Project

Chapter9. Conclusion and Reflection

This final chapter of this thesis consists of a set of reflections based on theory, technique, and practical cases. The first set of reflections on the extent to which the literature studies described in the preceding chapters address the specific research questions is presented, followed by the second set of reflections which is mainly based on fundamentals of SAR technologies and looks at their interactive capabilities and predict future scenarios. The third set of reflections deals with the practice of museum designing, which includes general exhibition narration and augmented space making. Finally, a reflection on limitations and future work is discussed.

9.1 Theoretical Convergences

9.1.1 The museum in transition

With the aim to answer the first research question: In what ways has the scientific exhibition evolved from historical representations into immersive environments using augmented reality (AR) systems? The first part of the thesis reviews the literature about changes in cultural and historical perspectives of scientific exhibitions and those changing methodological implications for exhibition narratives inside the museum space. Despite the limits of material representation and the subjectivity of multiple narrations, museums allow visitors to partake in the objects/exhibits' histories while reflecting on them imaginatively. At the same time, museums of science are gradually shifting focus, from object-centric towards experience making, which has profound consequences on the founding premises of science centres.

From the literature review from Chapter 3, science museums took centuries to evolve from knowledge-imparting institutions to sensory experiential spaces. There are two causes for this transformation: One is that collected scientific objects alone are no longer sufficient to stimulate museum learning, and specifically to engage visitors' attention; thus, the need for constructing new exhibition narrative with interactive media and digital technologies has gradually emerged. The other cause is that museum environment, in becoming public institutions, has somewhat prioritised people and their values over the significance of objects. These changes have consequences on: the museum visitors' interpretations, the collected objects, the exhibition itself, and the underlying premise(s) and authority of museums as pedagogical institutions.

In addition to representational strategies and conventional physical displays that help translate the curatorial interpretation (constructed narrative) into physical form, there are other relatively new forms of presentation, which are largely enabled by technological advances in reproduction (Brett, 1996), archival (Ersnt, 2000) and design techniques. Paired with the intention to create entertaining sensory experiences for wider audiences, new media and technologies are being increasingly introduced and integrated into narrative-oriented exhibitions. This can be seen in the form of sensor-activated audio-visuals and touch-screen computer interactivity (McLean, 2004). These new forms of presentation can be defined as "a set of tools and technologies... used to create new applications or perhaps even enrich existing ones through the merging of sounds, moving images, graphics, animation and computing, under the control of the user" (Fahy, 1999).

The author also notices that many researchers have questioned about the validity of the word 'Interactive', especially for each visitor's personal and subjective interpretation of reality derived from the contrived (digitally-enhanced) exhibition experience. Hein regards the trend of technology integration as the museums' attempt to control 'the conditions under which visitors can be expected to have the experience' (Hein, 2000). The main criticism has to do with the inclusion of new media and advanced technologies for experience making, which has been widely adopted and/or implemented without having established a clear set of standards or proof of the value they add to the experience. Second, with the museums' focus on making experience via digital technologies, the collected objects, more than ever, become means to corroborate the curator-constructed narrative. The objects themselves potentially lose their factual integrity as their own provenance and meanings become secondary to their effect on the presented subject. Third, the trend towards technology integration also affects scientific exhibition itself, particularly its purpose. Exhibitions are no longer conceived as solely conveying information on the subject, but instead as stimulating an effect or experience for the visitors through the integration of new media and advanced technologies. And this could lead to the re-conceptualisation of authenticity in which the audiences interpret exhibition-evoked feelings and simulated experiences as the real thing, not 'the collection of scientifically legitimated objects'. As Hein (2000) discusses two additional implications of experience-oriented exhibitions (a) a change in the communication style of the science exhibition, through which the story is "elicited rather than told", and (b) a change in the definition of an exhibition, where the collecting and displaying techniques are replaced by the experience making technologies.

Through the literature research in Chapter 3, the author captures the relation between science museum evolution, museum space, technology development and representational strategies; it reviewed how historical context and cultural perspectives on science museums emerged and developed in past centuries. And at the end of this chapter, the author starts to bring the key word of this thesis - Augmented Reality (AR), they are promising technologies which have the wide impact on creating new interaction approaches in the museum environment. AR is not commonly associated with traditional singular Human Computer Interaction (HCI). Instead, it provides direct displaying information related to real objects and projects into the real museum environment. This new spatial format has proved to be a great augmented/enhanced method to attract the museum audiences and increase their engagements, interests, and usability.

9.1.2 A new poetics of augmented space

In order to answer the second question: How to re-conceptualise augmented space from relating AR theories? The author digs into the development, evolution and fundamental components of the AR world. Theoretically, Milgram and Kishino (1994) were likely the first to define augmented reality as situated on a reality-virtuality continuum, between the so-called authentic world on one end and full-scale virtual reality on the other. Their seminal piece surveys the nascent stages of mixed reality development and, like Weiser (1993), influenced a wide spectrum of researchers from a diverse array of disciplines, from Japanese computer engineers (Tamura et al., 2001) at the fore of technology design to education technology researchers (Hughes et al., 2005) to science and technology studies scholars (Star, 1999; Sassen, 2006).

In contrast with wide range of researches in augmented reality, not many people mentioned those embodied hybrid spaces which flow between digital and physical layers. It was first defined as 'Augmented

Space' by Lev Manovich in 2002, which represents digital information and interaction opportunities that sits on top enhanced and augments the original physical environment. Lev Manovich has long been concerned with the boundaries between art, communication, interaction, and new multimedia space, especially where information is interacted with wirelessly and, building upon the work of Weiser (1993), the focus has shifted from the human-machine relationship to more complex scenarios of social interaction with distributed technologies. Manovich is not necessarily commenting about or making reference directly to augmented reality, but about spaces that facilitate a material-virtual blurriness. His primary thesis is that augmented space, which he defines as physical space overlaid with dynamically changing information, isn't so much a technological interaction, but a cultural and aesthetic practice. At a more fundamental level, he wonders about the immaterial nature of new information flows within existing physical structures.

Ultimately, Manovich (2006) suggests that designers must start treating the invisible space of new media as something substantive. But he doesn't focus merely on spatial questions. His anchor is the role that changing media practices has in arranging and bringing together groups of people. In 'The Language of New Media', Manovich describes a fundamental impulse of new media: that it remediates - that is it translates and refashions - other media, both in content and form (Manovich, 2002). Manovich asks, toward the end of 'The Poetics of Augmented Space' (2006), whether cultural institutions can play an active role as laboratories for testing alternative futures. It anchors the base of this thesis, as the author is fundamentally asking whether institutions like science museums can accommodate experimental and innovative narration of new AR technologies within the original space, as a new embodied spatial form.

However, what is the material substrate that AR is inscribed upon in the augmented space? Where does it reside? How do we understand and abstract new concepts of augmented space? Chapter 3 reflects on the fundamentals of the AR systems, including 1) Display system; 2) Sensing, tracking and registration; 3) Input and interaction techniques and 4) Virtual content creation and rendering. Through articulating each component of the AR system, it developed a practical instruction for museum designers, especially with regard to how this AR technology can be used to illuminate invisible processes and networks, beyond merely using it to annotate objects/exhibits or their environments (a prevailing early focus of AR).

Borrowing from the historical review of the AR literature and the technological review of the AR system, the new poetic of augmented space is summarised as three fundamental characteristics:

1. Bridging physical and digital
2. Mediating social and cultural changes
3. Transforming ‘space’ to ‘place’

The description of each characteristic is detailed in Chapter 4, the focal point of this research is to investigate how museum visitors perceived ‘senses’ of an augmented place can be amplified through digital means. Informed through AR literature, this thesis in particular explores new opportunities through AR technologies with physical space. This embodied augmented space enables people to bridge temporal, spatial, and socio-cultural barriers and make meaningful experiences in and through physical places, which would not be possible otherwise.

9.1.3 Augmenting space for the museum learning

In terms of AR technologies for museum learning, through literature researches, the author learned that museum nowadays using a variety of spatial embedding technologies (Belcher, 1991; Miles et al., 1982; Fahy, 1999; Hsi & Fait, 2005; Hornecker & Stifter, 2006; Dindler et al., 2009). As they are presented in Chapter 5, researchers and educators nowadays seem more ready to accept the trend of technology integration and take more attention to consider about its potential for learning inside the museum space. For example, Fahy (1999) and Hornecker & Stifter (2006) discuss the effects of augmented technologies in terms of museums and information. Traditionally the services provided by science museums have been object-based activities such as exhibitions, which can be highly subjective. However, the information associated with the collected objects is becoming more significant with the changes towards a more democratic approach in curatorial interpretation. New AR technologies, in the form of automated documentation systems, greatly facilitate this need by making both the collections and their information more readily available. As Fahy (1995) asserts that:

> "While it is true that objects are central to the museum, indeed they are what sets the museum apart from other leisure and educational attractions, the importance of the objects lies in their cultural or environmental significance. Axiomatic to this is the need to 'record the significance of the object in a manner [that] is usable and can be protected for the future...The real value of museum is in the preservation not so much of the objects themselves, but of the information relating to them."

AR technologies are therefore critical to this type of change, particularly in terms of research process. Nonetheless, most researchers still consider "interactive devices and AR elements [as having] an active and important role to play in the learning process". The main advantage researchers see in new technologies is the possibility for users to access information in a nonlinear way or through links, which is more similar to the way we think. Much of the literature suggests that the trend towards augmented space in museum exhibitions is accompanied by a change towards considering exhibitions as communicative media instead of as conventionally didactic.

In general, there are two ways of analysing pedagogical approach of augmenting space as a process of knowledge transmission. First, refers to the transmission model of communication to help explain the museums' approaches to their exhibition development. According to Hooper-Greenhill, there are several issues with the current practice of modern science museums. Exhibitions are often developed based on the curator's knowledge and decisions without much consideration of the museum visitors, the audiences are in fact "rarely defined beyond the catch-all general public" (Hooper-Greenhill, 2004). The current communication process is often one way and from the technical-process perspective (involving mainly object selection, artefact arrangement, and space layout). The focus on augmented space in exhibitions thus not only neglects the social and cultural aspects in communication, but also excludes visitors' individual preferences. Second, in looking at exhibition communication as a part of culture, the thesis also discusses the importance of the interpretation process-the construction of meaning. It emphasises that this approach largely depends on "how culture is defined and how social interactions are conceptualised". (Weil, 2002;

Hooper-Greenhill, 2004). It also acknowledges the notion of entrance narrative (each visitor's variable preconceptions) and how it contributes to different meanings.

In Chapter 5, the author studied museum learning from three individual perspectives, which includes contextual model of learning, free-choice learning and constructivist learning. As many authors advocates the need for visitors to construct their own interpretation of an exhibition (Ernst, 2000; Weil, 2002; Hooper-Greenhill, 2004), and therefore argues for less control by the curatorial staff. However, further research is recommended to investigate how far interpretive strategies, including narratives and design, influence the visitors' actual interpretations. This thesis encourages museum curators/designers to embrace changes by taking on new approaches in digitally / spatially augmentation to lessen the gap in the museum-audience relationships. There are four suggested changes (a) the involvement of new professional roles from various disciplines, (b) the recognition of differentiated audiences, (c) the introduction of new voices as a result of acknowledging the diversity of the audiences, and (d) the development of new narratives that are less complete and more open to various interpretations.

From those researches, the author concludes that augmented space is well aligned with nowadays constructive learning notions in the museum field. Using augmented space to replace traditional guides in museums means the museum experience is moving from didactic or instructive to active or discovery learning. However, combining with the field observation from case studies, the author found that achieving realistic, believable stories and curriculum modules in the augmented is, and should be, a foremost concern for those researching cognition and learning, careful attention must be paid to the roles that narrative and storytelling have in designing and developing digital augmentation for museum education.

9.2 Technical Implications

9.2.1 Fundamentals of spatial augmentation

With the development of AR and Spatial Augmented Reality (SAR), as stated in the beginning of the thesis, researchers worldwide increasingly draw on the diverse insights of ergonomics, sociology, developmental psychology and educational theories, to ensure that the embodied hybrid space with prove to be educational as well as entertaining. At the same time, as author states in the end of Chapter 3, the introduction of different AR and SAR devices for augmenting physical layer, requires studying and experimenting with the technology's possibilities and affordance.

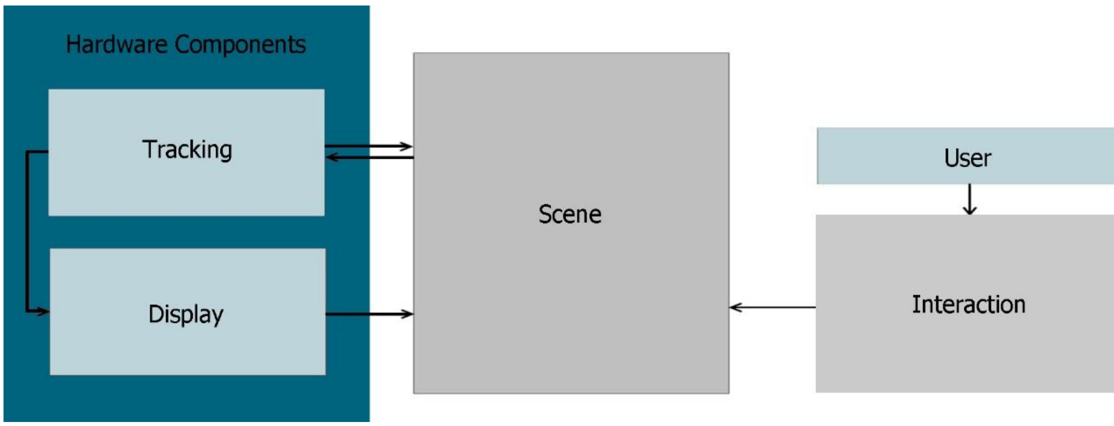


Fig. 9.2.1-1: A preliminary design of SAR system's operation.

Based on the exploratory research, the figure above (**Figure 9.2.1-1**) concluded the skeleton of a SAR system. In the diagram, the user inserts input through some means that enable the interaction between visitor and surrounding space, resulting in a change of state. This change takes place on the scene and the effect is recorded by the tracking system. After some processing, the corresponding information is then projected back in the scene. Based on the aforementioned and the components forming the SAR system displayed in the Figure, the research continues with an elaboration on the system's basic components (interaction, scene, technology and application). With the research from case studies and design-based research, a more complete view of the SAR system's operation for museum designers is demonstrated in **Figure 9.2.1-2.**

The author also noticed there are technical and spatial constraints with SAR that should be taken into account. As Ueli Maurer et. al. (2003) pointed out that "the embodied augmented experience would be something that is really important to get right in order to understand the AR device in context of the space that is being used, particularly if you have content or media that is location-based, or triggered by proximity - and for the museum space, that is really important." Pallud and Monod (2010) echo that spatial augmentation is perceived as a necessary criterion to have a positive experience in museums, which includes multi-sensory as well as physical, virtual and context-aware interaction. The spatial augmented application should be able to position a user in a space and deliver content that is appropriate to that space.

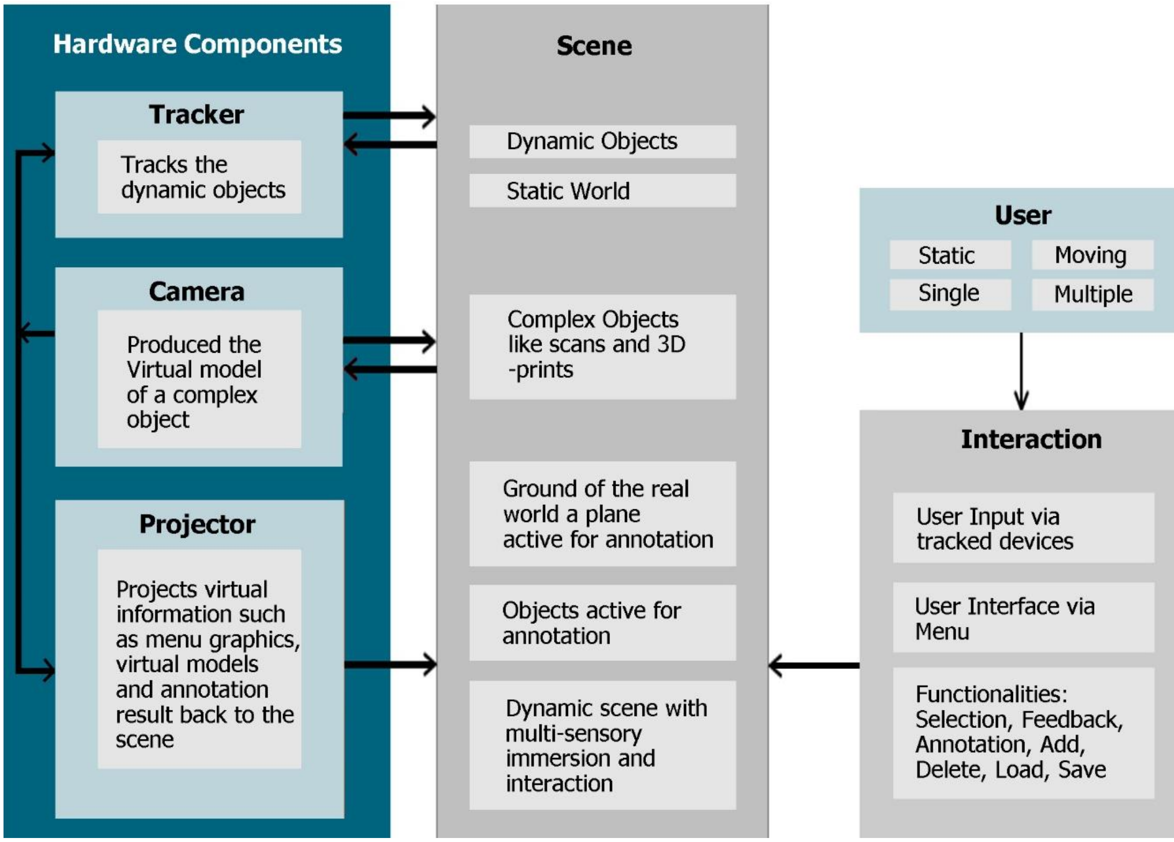


Fig. 9.2.1-2: A more complete view of the SAR system's operation which is demonstrated here.

Many researchers like Dourish (2001) and Kjærgaard et al. (2010) were dismayed after having evaluated the digitally augmented layer for a location-based application, noting that, aside from concerns about its lack of precision in a bounded, indoor museum environment, the interface "didn't really convey the topics and information" that he was hoping to get across (Dorish, 2001). That said, there is still a considerable challenge to adopt SAR in a museum environment. As Kjærgaard et al. outline some of the misconceptions and challenges with using indoor GPS positioning, but they highlight the point that both the number of walls and construction materials used in a building can each have a significant impact on signal degradation, something which is crucial for museum designer and developers to consider (Kjærgaard et al., 2010). However, as it is suggested by the Digital Curator - Zara McKenzie in HKD studio, using the biometric data collection (like eye tracking; gesture; gait analysis and voice recognition) to determine contextual cues can be an alternative way to effectively embed SAR systems in museums.

At the conversation with Richard Houghton[31], Paul Mumby[32] and Zara McKenzie[33] for DBR project, they all brought up the tremendous tracking potential inherent in SAR, although Richard seemed more concerned about the privacy and surveillance angle, while Paul and Zara was more interested in building spatial-dependent interactions that would require knowing where and when museum visitors were moving around inside an exhibition gallery. The author believes that museum designers should be excited about being able to track visitors for the purpose of driving simulations, where their position relative to an exhibit, augmented space or exhibition zone in the gallery would have some meaning in the activity they're engaged in (an HCI approach that could lend itself beautifully to a mixed reality experience).

9.2.2 The interactive learning capabilities afforded by AR / SAR technologies

The interactive capabilities afforded by new technologies in educational contexts are wide and varied, from simulation, to communication, to convergence of multiple interactive technologies (Collins and Halverson, 2009). Wood and Latham (2011) emphasise the role that embodied engagement within augmented space can play in the meaning-making process, arguing for a phenomenological approach to touch in a museum setting. "One of the familiar tropes of touch is a person reaching out to feel (with the hand) an object to determine if it is 'real,'" they write. Visitors may do this to verify, to prove, or to reassure oneself that the object is what the eyes perceive it to be. Haptic and tactual feedback may provide rich opportunities for meaningful interactions in these settings. Larssen et al. also (2007) note, of interactions with tangible

[31]. Richard is the Creative Director of HKD, he is in charge of content programmer and new media initiatives, he has worked in youth education programming and researched topics like digital literacy and storytelling. He is currently part of a team designing a large public augmented reality project.

[32] Paul is an Exhibit Technologies in HKD, he is a former teacher, and faculty member in a biomedical communications department at Goldsmiths College, University of London. He has a long-standing involvement in science education.

[33] Zara is a Digital Curators in HKD, and an experienced developer of digital media content and founder of an interaction design company that has recently installed major exhibits in prominent museums and science centres around the world.

objects taking place within bodily reach, an important characterisation that denotes those "taking place on, near or fairly close to the body," could facilitate better learning experience.

Those findings are strongly associated with literature reviews in Chapter 4.2 and the descriptive research with two museum cases, the author found that promoting self-exploration and build up the link between space, the exhibit and visitor themselves is rewarding. This construction of knowledge is based on an interaction between subject and object, through perpetual exchanges of thought and different kinds of experimental interaction. Moreover, based on the book - *Game Feel - A Game Designer's Guide to Virtual Sensation,* Steve Swink mentioned "…eyes, ears, tactile sense, proprioception – there is no separation when a person perceives something… (Swink, 2009). This tells us that an interaction becomes an experience that is based on the total combination of visuals, sounds, proprioceptive sensations and tactile sensations.

In summary, augmented reality (AR) and spatial augmented reality (SAR) offer new ways for museums to enhance the experience of visitors and is already being widely applied in museums, offering the possibility of adding a virtual layer to the actual room and physically present artefact. A successful augmented experience combines actional, symbolic, and sensory factors in order to maximize the participant's suspension of disbelief that she or he is "inside" the digitally enhanced setting. Actional immersion involves empowering somebody within an experience by offering certain abilities impossible in the real world. In a museum setting this could mean giving visitor the ability of flight, surfing or simply a magic touch.

The model below (**Table 9.2.2-1**) concludes principal characteristics of interactivity in the museum using three dimensions: apart from physical characteristics, interaction process and behaviour of the visitor are also two essential parts in activating the whole system (based on Kiousis, 2002). For a high interactivity level, the interactivity process should be reciprocal: the messages of sender and receiver should be related and there should be a high level of feedback. The physical characteristics of the object should stimulate multiple senses (eyes, ears, tactile sense, proprioception…) and offer several layers and options to explore. Last but not the least; it is also important that the subject and content of the augmented space design are relevant to the visitors. They should be encouraged to actively engage in the interaction, and the engagement with augmented space should take place on multiple levels with different learning capabilities.

It is important to consider the specific types of visitors to be able to create a suitable experience with different interactive learning capabilities. And the author believes that putting the visitor in the focus while planning a museum exhibition with AR in the beginning can lead to innovative concepts which will encourage more active visitor participation in the final exhibition setting.

Interactivity in a museum						
Interation process		Physical characteristics of the object			Behaviour of the visitor	
Feedback	Reciprocity of message	Different options to explore	Sensory stimulation	Relevant subject and information	Sensory, emotional and / or intellectual engagement	Active

Table 9.2.2-1: Interactivity in the museum

Source: Adapted from Kiousis, 2002

9.3 Practical Reflections

Practical reflections are mainly based on the DBR of this PhD study. As mentioned at the end of Chapter 7, due to the variety of museum contexts, particular concepts and perspectives cannot be easily translated into specific "guidelines" or "requirements". However, the 'sensitivities' here suggest relevant issues and inspire creative design, rather than imposing rigid rules on the design. Sensitivities do not impose pre-determined solutions, but rather define spaces for discussion on how the design could deal with the issues that they express in the practical world.

9.3.1 Guiding principles and design sensitivities for general narrative design

A) Interpretive Strategies

- Exhibitions should be conceived and developed around a "big idea," as well as the framework on which to build a more detailed understanding of the subject.

- Exhibition messages should be crafted to ensure content relevancy and exercise discipline and restraint in content presentation.
- When effective or useful, exhibition teams should experiment with creative ways of organising content that move beyond traditional chronological or subject categorisations or object classifications.
- Exhibition content should benefit from user-contributions and dialog with potential audiences that can be facilitated by mobile, social media interaction and feedback.
- Educational programs and digital outreach are integral to exhibition interpretive strategies, and need to be part of exhibition development from the outset.
- Exhibitions should have as their foundation the peerless aerospace collections and leading research assets in history and science.

B) Visitor Experience

- Key to a successful visitor experience is variety, resulting in a diversity of exhibition experiences and 'entrées' to content to engage the broadest range of visitors possible.
- Defining the specific audiences for individual exhibitions should be done early in the planning process, as it will govern many factors in the development of the exhibition—content, messages, design, interactives, etc.
- Exhibitions should accommodate a broad range of learning styles and engage as many senses as possible.
- Multiple presentation formats should be employed where appropriate to deliver the ideas, information, and messages. Content development should be approached with all these formats in mind simultaneously, not from a text point of view first and then adding other elements after.
- Label text should be presented in a tiered format, making major ideas down to detailed information accessible in an effective way at the discretion of the visitor. Family labels or directed learning labels should complement and support the main text to further increase audience accessibility to content.

- The exhibition should provide the possibility of collaborative discovery and of making comparisons in order to support collaborative understanding and discussion of objects. As we observed during those two augmented spaces, the interactivity supported by the exhibition should not be limited to that between individual and exhibit, but we should consider the different degrees and combinations of verbal and gestural interaction amongst individuals.
- Interactive elements, digital and mechanical, should be created to support content and messages in an integrated way, providing a broadened learning experience. Touchable and audio features, and other innovative exhibit technologies, should comprise the package of multiple presentation elements where useful.
- Exhibitions should create environments that are conducive to social interaction, both among visitors physically present in the gallery, as well as through digital social media.
- Exhibitions should be conceptualised as a creative entity that is comprised of physical and digital elements, accessible and engaged with in a variety of ways.

C) Presentation Philosophy

- To keep the user's interest and engagement high, ways to support different "layers of activity" with AR technologies should be envisaged. The final presentation should provide visitors the opportunity to engage with the exhibition in a flexible, non-prescriptive way, to decide the level of their involvement in the exhibition. Each interactive element of the exhibition should provide successive surprises and discoveries for the visitors. Design and fabrication of exhibition spaces should also give consideration to programming and special event activities.
- Exhibition design and fabrication should be attentive at the outset to effectively and economically modifying or upgrading exhibition elements over time, as well as performing required maintenance.
- Large, comprehensive, long-term exhibitions should be complemented with smaller projects to accommodate more focused subject matter; short-term topical exhibits; and experimental projects to test content approaches, interactive concepts, exhibit design ideas, or materials. To facilitate

this, create a number of smaller and physically flexible exhibit spaces to broaden the variety of presentation capability.

9.3.2 Interdisciplinary insights on augmented space design

Reiterating the author's points from Chapter 4.4, that the emergence of AR is a complex process that requires a holistic stance to effectively study if we want to distill effective design practices and recommendations. Furthermore, it is a topical and relevant discussion that spans the education spectrum. Having attempted to take these things into consideration, the author wants to offer some recommendations derived from the analysed data from case studies and DBR, as well as the experiences from the industry:

- There is no established AR canon based on a single or small number of disciplines, AR researchers need to draw from computer science, human-computer interaction, digital media, learning sciences, museum studies, performance studies, information, and communications - not to mention the various humanities disciplines that increasingly interact with the technology, from history to anthropology.
- A host of educational considerations and criteria need to be accounted for before AR should undergo any kind of full-scale implementation, such as: how well it fits with the curriculum; whether or not supplemental tangible materials and objects are available to support the digital content; and how well it takes into account spatial and contextual constraints. Recalling discussions and reflections in Chapter 5 and Chapter 6, it is critical in a space like a science museum, to employ a structure akin to their narrative mapping technique that can integrate spatial and technical considerations along with questions about how different group sizes interact at stations, and whether there is adequate time and access for technical help. This will help designers effectively model the information or learning space in a way that reflexive changes can be implemented at all levels.
- Taking into account the availability of physical layer that can still be perceived by visitors and interacted with, successful AR technologies should be a support for (or an enhancement to) existing

physical environments, not a replacement. While AR can potentially act as an affordable stand in for a variety of expensive and difficult to maintain artefacts, it remains a generally visual-perceptive medium (for the time being). In this sense, it is congruent with the "touch with the eyes" paradigm that is common in many museums. As more multi-sensory AR becomes available, things like haptic feedback from AR-enabled objects become accepted, a great deal of care will have to be directed toward imagining how something like touch can be better incorporated in technology-enhanced exhibits. Wood and Latham (2011) call for using phenomenological touch to provide opportunities for visitors to "open avenues for greater access, appreciation, and awareness of the lifeworld through transactions with objects." In the context of haptic feedback-enabled or physicality-enhanced AR, this could extend those opportunities to interact not just with the materiality of objects, but with multiple layers of information that could be associated with the object in a way that isn't distracting or overwhelming.

- The AR system of the augmented space needs to accommodate different user groups and people of all ages, appeals to children and adults alike. The exhibition should also support interaction from visitors with different levels of knowledge and expertise about the Collection, and involve equally visitors with different degrees of knowledge and interest.
- The augmented space should support the group visit experience with appropriate. The possibility for the visitors to talk to each other must also be ensured, as discussing the objects together is an essential part of the group experience. It should dawn upon museum designers that devices as HDM (Head Mounted Displays) or headphones are not appropriate for such space, and they need to avoid designing singular human-computer interface which isolate each museum visitor as well.
- Being an augmented space where active engagement is supported, it should present, elements that provoke feelings of comfort and friendliness thus encouraging people to participate. In another word, the look and feel of the space should encourage the visitors to perform activities such as debate, exploration, and discussion. Each individual should be encouraged to take part to the activity around the augmented space. The designed augmented space should also give children

the possibility to lead the process of discovery and to communicate their findings to their companions.

- The interaction design of the augmented space should provide unique and attractive visual interfaces, spatial perception and physical interaction, which showing clear clues, triggers and adequate affordances to make visible which actions the visitors are allowed to perform on each component of the embodied hybrid space.
- AR has potential to make science education more engaging, but should not be introduced without caution. Related to this, based on the DBR in Hong Kong Space Museum, the author also realised that developers should not neglect the design wishes of users. Involving them in the design process can provide a unique opportunity to explore questions around materiality and simulation.
- Rather than assuming technologies like AR will blur the boundaries between formal and informal science education, the author states designers and content creators should be ready to accept that they may actually produce very divergent experiences, despite any collaborative design or development processes that are introduced to bring the two sides together. AR may actually enable learners to have far more rich and interactive experiences in science museum and centres that can be complemented by starkly different, but equally effective museum learning.

9.4 Research Limitation

At the onset of this PhD study, the research coved a relatively wide scope, aiming at interconnecting museum experience and exhibition design, more specifically; the thesis tries to explore the innovative narration for augmented space inside the museum environment. This section will address these limitations as well as propose future avenues for research.

The first limitation of this research was stated in the research methodology in Section 6.2, the limited number of case studies could hardly generate comprehensive on-site results. As the field research stage of this PhD study was completely self-funded, all the on-site observation, user surveys, interviews, and onsite data collection, were conducted by the author independently within a short-period of time[34]. For practical reason, the research scopes of case studies were limited to two galleries (one of each). Those two exhibition galleries focus on two relevant scientific exhibition themes with different interactive exhibit contents. While this has potential advantages in that it removes audience differences between museums as a potential confounding variable, it also means some results may be theme-specific, site-specific, and not applicable to other settings. Moreover, there are numerous barriers and challenges for getting both spatial analysis and user behaviour analysis in details with limited time and money. For instance, to obtain access and permission of these two science centres to take questionnaires and formal interview were both denied by museum authorities, the website analysis is adopted as an alternative source for understanding visitors experience inside two museums, essential conclusions were drawn using Tripadvisor.UK as the main source, which may need further consideration on different types of visitors and their ethnographic approaches in visiting, playing, perceiving and learning.

The second limitation is related with the Design-based Project (DBR) for HKsM. As mentioned in the Research Scope, given the research focus on the influence of design elements on the conveyance of the indented information of an exhibition with AR technologies, the scope of this DBR research is limited to the relationship between curatorial interpretation and final representation of the augmented space the author designed and prototyped. Audience survey is beyond the scope of the intended investigation. This is also because the Hong Kong Space Museum project is still under construction at the moment. Thus, it is impossible to get Whilst-use evaluation and Post-use evaluation from real visitor groups inside HKsM. However, with the aim to interconnect the early curatorial interpretation and the final experiential representation, the author conducted two phased prototype studies with HKD studio: the first phase was rapid prototyping with three feasible concepts in augmented space development after ideations and initial selections; the second phase prototype study was set up as more finalised version focused on the Galaxy Surfing Experience. However, both user involvement sessions were planned and conducted with 20

[34] The field observations were carried out over a period of two months during (October-November, 2015) and include monitoring visitors and their interaction with the exhibition as well as studying the facilities, spatial qualities and architectural factors of the MAGNA site.

participants, and all the participants were recruited in UK. So the participant sample may not be representative of visitors to HKSM as whole. Furthermore, culture and socioeconomics difference between the post-colonial Hong Kong and the United Kingdom may need further research and discussion.

Despite these limitations, this research has successfully achieved its overarching aims by providing the insight into 1) museums in the technological landscape; 2) fundamentals of augmented reality and spatial augmentation; and established a new paradigm for 3) augmented space-making inside science museums. Together with comprehensive spatial and digital enhanced methods, which can help museum designers to cope with the complexities of multi-disciplinary interactive exhibition narration in practice. Through this thesis, the author also highlights three different dimensions the museum experience, and further generate design solutions which bring novelty from both spatial and technological perspectives to co-productive exhibition-making.

9.5 Future Works

While the author believes the findings outlined in this thesis to be of significant value to researchers in many different fields, she also recognises limitations in the scope of this work, from the duration of case studies to the sample size of the BDR project. Testing the verifiability of some of these findings longitudinally will be challenging, but this final subsection going to offer some thoughts on how the future research might go about doing so, as the author believes there is room for plenty of interesting future research.

9.4.1 Ethnographic approaches

Coleman's survey of approaches to understanding digital media connects digital media to an academic sphere, ruminating on how to best study the impact of digital media interactions and augmented spaces within and between different academic disciplines (Coleman, 2010). She operates from the principle that to best grasp the broad significance of new and digital media, we should use various types of analysis, always paying attention to the contexts in which the media is experienced. Coleman suggests that long-term ethnography is an appropriate tool for teasing out the deep and rich variability of digital media in everyday life. Understanding the people and contexts associated with new media adoption, and not just the technologies and devices, is something developers as well as researchers should strive for. She writes about the imbricated relationship between culture and access, noting that researchers should pay heed to the multiplicity of protocols for organizing knowledge (Coleman, 2010). Digital media is a lived and experiential phenomenon, as disembodied as that experience often seems. Ethnography in both science centres and science classrooms, especially long-term, deeply-embedded study where the researcher has a chance to fit in to the environment, would be useful to evaluate some of the findings of this research, as it is specifically interested in digital media and the technologies that support it (which generally change at a fairly rapid pace, as do the skills and tactics of developers). A subject like cross-generational adoption of a technology like AR could be better understood through long-term study, especially with regard to changing attitudes among educators. Simply placing technology in the hands of users and watching how they interact with it is not enough. Getting to know whether they are already familiar with the medium, what sort of assumptions influence their adoption of it, how they make it more personal, whether there are cultural or linguistic factors that help or hinder adoption of the technology (e.g. studying whether students whose first language is not the one being used to guide the learning have different degrees of interest or difficulty with the technology) - all of these are subjects that require a focused, in-depth analysis, that pays attention to social and cultural factors, something ethnography is appropriate for.

Moving from an ethnographic investigation that operates from a broad visitor studies perspective in a science museum toward one that works more closely with a host of returning and less transient groups, from school field trips, to weekend workshop participants, to summer camp participants, a researcher would have an opportunity to assess changes in AR technology adoption over a fixed course of time. Falk (1999), in describing a study of school field trips to science centres, writes that one of the findings was that students exhibited knowledge that "was clearly constructed and developed from a rich variety of related learning experiences, including interacting with parents and other people in enrichment and extracurricular activities and in more informal interactions at home, like playing with and disassembling electric, motor-driven toys and using iPad; and participating in school and museum-based experiences." Getting a handle on this rich sphere of interactions with people, institutions, materials, and technologies would only help push this sort of research in a thoughtful direction.

Also, moving beyond science museum, to other museums where science content frequently comes into play, from historical and cultural museums that exhibit the tools of scientific revolution, to art museums where learners can gain knowledge about material or visual culture, to folk museums where visitors might gain a broader understanding of a specific scientific practice. An ethnographic study might offer a chance to see how learners treat the subject of scientific knowledge and how we construct the space with advanced AR and SAR technologies, and look at how it is enhanced by interactions with different disciplinary subjects. Of course, this still places science content at the focus, but some of these findings can be measured across a wide spectrum of content in the augmented space.

9.4.2 Culture and socioeconomics

What sort of collective cultural differences / bias may be produced by designers and developers of AR technologies coming from European and North American backgrounds relative to those coming from growing software development hubs like China? While the phenomenon of science museum development in China and Southeast Asia that has run parallel to rapid economic growth, and if you look across China at the moment, there’s an absolute explosion of palatial and grand cultural institutions, and among these the science centres are quite prominent. However, although these new-built science museums are palatial, grand, huge, magnificent, the people behind them don’t have, as a generalisation, much idea about how these institutions service the communities and societies in which they are embedded.

For that reason, identifying a proposed science museums development in China and engaging in a long-term study of its planning and implementation in order to study whether these sorts of trends - palatial, grand buildings without strong connection to their local communities - could be rewarding if such a site were to focus primarily on digital media development, or rely on it for showcase pieces. That said such research would greatly benefit from local research celebrations, excavating cultural and linguistic connotations that contribute to the nuanced visitor experience. Briseno-Garzon and Anderson et. al (2012) have written about the need for Latin American researchers to conduct similar localised research with respect to how visitors interact with science museums in Latin American countries. The same recommendation could be made for research in HKsM, while Hong Kong has largely kept its distinct political, legal, and social systems; the cultural, political and socioeconomic influence of the Mainland on the city has grown enormously after 1997, and it has been 20 years until now. To conduct Pre-use evaluation, Whilst-use evaluation and Post-use evaluation in the Hong Kong after the construction and to compare the findings with respect to new museum developments in UK would be worthwhile.

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(Appendices & Supplemental Material)

Contents

Appendix 1 - The List of Science Museums for Case Studies

Name	Summary	Themes	Type	Ecsite-uk membe	Website
All Hands and The Bridge Interactive Galleries	Home of the Prime Meridian of the World, The National Maritime Museum tells the story of Britain and the sea, and the importance of the oceans in our lives. The interactive galleries are themed around the lives of seafarers and the skills and technologies they used.	All Hands Gallery: life at sea The Bridge: skills and technologies used at sea	**Museum** 16 galleries/exhibits Exhibition area: 1600 m2 Size: M Opened: 1995 and 2005	✔	www.nmm.ac.uk
Catalyst	Catalyst looks at chemistry and industry in 3 interactive galleries. Scientific—chemicals and their uses. Birth of an Industry—history of the chemical industry. EcoQuest—the environment. Catalyst also has a public interactive science theatre and a school science laboratory.	Chemistry Industry	**Science Centre** 100 exhibits Exhibition area: 1000 m2 Size: M Opened: 1989	✔	www.catalys.org.uk
Centre for Alternative Technology	CAT aims to inspire, inform and enable people to explore more sustainable ways of living. CAT also runs practical residential courses all year round, hosts school visits and provides a free information service.	Sustainable living Alternative technology Organic gardening	**Other centre** Size: M	✔	www.cat.org.uk
Centre for Life	The Centre for Life is a vibrant and exciting place where science is explored and debated. From exciting hands-on exhibits, family activities to lively lectures and serious debates on contemporary science issues, Life offers something for all ages and interests. As a regional focus for science communication, the Centre encourages curiosity about science by questioning and uncovering new things about life and the world around us.	Life sciences	**Science Centre** 50+ exhibits Size: L Opened: 2000	✔	www.life.org.uk

The Centre of the Cell	Opens March 2008, website launched March 2007. Centre of the Cell is a unique interactive multimedia experience embedded within a working research laboratory. The central themes are cell biology, disease and biomedical research.	Cells Biology	**Discovery Centre** Size: S Opened: 2008	✔	www.centreofthecell.org
Clore Natural History Centre at WML	One of the attractions at World Museum Liverpool. Touch a hippopotamus skull, examine an exotic tropical butterfly or hold a mammoth tooth. The centre is packed full of mounted and preserved specimens of all types of animals from around the globe. There are also rocks, minerals, fossils and plants to see.	Natural History	**Discovery Centre** 20,000+ exhibits Exhibition area: 120 m2 Size: M Opened: 1989	✔	www.liverpoolmuseums.org.uk/wml/naturalworld/nhc
The Deep Millennium Project	Taking the theme of the world's oceans, The Deep tells the story of the oceans from the beginning of time to present day and into the future.	Oceans	**Other centre** Size: L Opened: Mar 2002 and 2017	✔	www.thedeep.co.uk
Discovery Museum	Discovery is the largest free museum experience in the North East. Full of displays and interactives that bring science, technology and history to life.	Science History Fashion Military Maritime	**Museum** 60+ exhibits Size: L	✔	www.twmuseums.org.uk/discovery
The Eden Project	Eden explores the relationship between people, plants and natural resources. 55-metre-high covered biomes have been built exhibiting plants from two climates: the rainforest and the warm temperate/Mediterranean together with outdoor displays from the cool temperate zones including UK.	Plants Experiential learning	**Animals/Plants** Exhibition area: 125,000 m2 Size: L Opened: Mar 2001	✔	www.edenproject.com
Edinburgh International Science Festival	The Edinburgh International Science Festival is Europe's largest public celebration of science and technology with around 180 workshops, shows, exhibitions, tours, talks and hands-on activities for young and old. It attracts around	Science and technology	**Travelling or Festival** Approx. 180 exhibits Size: L Opened: 1989	✔	www.sciencefestival.co.uk

	120,000 visits over 11 days at Easter-time.				
The Engine House Project	The Engine House Project runs a variety of half-day science sessions at Sandford Mill for Key Stage 1 and 2. Sessions include forces, materials, sound, light and electricity. Outreach to schools in winter.	Forces Materials Sound Light Electricity	**Museum** Size: S	✔	www.chelmsfordbc.gov.uk/enginehs
Eureka! The Museum for Children	Eureka! The National Children's Museum is an interactive educational museum for children in Halifax, with a focus on learning through play. It is run as an educational charity and not-for-profit organisation. Eureka! is based on the North American model of children's museums, aimed at families with children aged 0–11 and encourages hands-on inter-generational learning.	Science Music The body The environment	**Children's Museum** 200+ exhibits Exhibition area: 4,500 m2 Size: L Opened: 1992	✔	www.eureka.org.uk
Explore-At Bristol	The project opened in 2000 as the successor to the Exploratory, a science museum and demonstration centre, founded by Richard Gregory. At-Bristol is one of the UK's most exciting hands-on science centres! Discover interactive exhibits and special exhibitions, take in a Planetarium show or join our Live Science team for fun experiments and activities.	Science Natural history	**Science Centre** 150+ exhibits Exhibition area: 1500+ m2 Size: L Opened: 2000	✔	www.at-bristol.org.uk
Extra Ordinary Gallery	Snibston is Leicestershire's all-weather science and industry museum, where visitors can get their hands on over 90 interactives indoors and outdoors.	Biology Energy Weather Light Forces Engineering Mining Textiles	**Science Centre** 70+ exhibits Size: M Opened: 1992	✔	www.leics.gov.uk/museums/snibston
Glasgow Science Centre	Scotland's biggest science centre. Includes 4 floors of hands-on exhibits, IMAX and Space Theatre.	Science	**Science Centre** Size: L Opened: 2001	✔	www.glasgowsciencecentre.org
Go Experimental	With interactive exhibits, exciting science workshops, plenty of hands—on fun and	Energy production	Other centre 30+ exhibits	✔	www.go-experimental.com

at Sellafield Visitor Centre	Europe's first Immersion Cinema, Sellafield Visitors is the educational and entertaining day out for budding scientists of all ages.	Nuclear power The environment Science	Size: S Opened: 1989		
Green's Mill and Science Centre	Restored working tower windmill once owned and operated by mathematical physicist George Green (1793-1841). Adjacent science centre tells the story of the windmill and of Green's scientific achievements with hands on exhibits e.g. magnetism, light, electricity.	Maths Environment Magnetism light electricity	**Other centre** 15 exhibits Exhibition area: 100 m^2 Size: S Opened: 1985		
Hands-On	A hands-on science centre for all ages. Run by the Oxford Trust who also provide shows, workshops and a number of other resources to enhance the teaching of science, technology and engineering in the area.	Light and Sound Forces and Motion	**Science Centre** 40+ exhibits Exhibition area: 100 m^2 Size: S Opened: 1990	✔	www.oxtrust.org.uk/handson
The Living Rainforest	The Living Rainforest promotes a sustainable future through education and research on humanity and the world's rainforests.	Plants and animals Ecosystems Economics Cultures	**Animals/Plants** Exhibition area: 20000 m^2 Size: M Opened: 2000	✔	www.livingrainforest.org
The Look Out Discovery Centre	The Look Out Discovery Centre has over 80 hands-on science exhibits. Launch a hot air balloon, climb through our giant mole hole or play a tune on our string-less harp!	Science and nature	**Other centre** Over 80 exhibits Exhibition area: 730 m^2 Size: M	✔	www.bracknellforest.gov.uk/be
Magna Science Adventure Centre	Magna is set in Templeborough Steelworks in Rotherham. Inside you can explore the four elements of fire, air, earth and water and have fun firing giant water cannons, launching rockets, spinning in a gyroscopic chair, learning to fly, exploding rock faces and working real JCB's.	Fire Air Earth Water	**Science Centre** 120+ exhibits Size: L Opened: Apr 2001	✔	www.visitmagna.co.uk
The Manchester Museum	University Museum includes 'Science for Life', interactive exhibition about the human	Natural history Science	**Museum** Size: L		www.museum.man.ac.uk

	body (previously at Wellcome, London); Discovery Centre; Fossils Gallery; Meteorites and minerals; Vivarium and Aquarium.	Archaeology Ethnography	Opened: 1885		
The Museum of Science and Industry in Manchester	Based in the buildings of the world's oldest passenger railway station, thirteen action-packed galleries bring the past to life with working industrial machinery, scientific achievement, live demonstrations and hands-on exhibits.	Industrial heritage Scientific achievement	**Museum** 60+ Galleries 33 exhibits Exhibition area: 600 m^2 Size: L Opened: 1988	✔	www.msim.org.uk
The National Botanic Garden of Wales	Plants and Water Discovery centre. Independent centre.	Plants Science	**Animals/Plants** Size: L		www.gardenofwales.org.uk
The National Marine Aquarium	The National Marine Aquarium is a charity dedicated to increasing awareness and understanding of the oceans, the life they contain and the way that humans affect them. It is Britain's largest aquarium containing Europe's deepest tank.	Aquatic Life Human Interactions with the Oceans	**Discovery Centre** 52 exhibits Exhibition area: 5500 m2 Size: L Opened: Jul 2002	✔	www.nationalaquarium.co.uk
National Museums Liverpool	National Museums Liverpool is a group of eight museums and galleries dedicated to the promotion and enjoyment of art, history and science. The venues are The Conservation Centre, Lady Lever Art Gallery, Sudley House, Museum of Liverpool Life, HM Customs & Excise Museum and The Walker.	Natural History Centre Planetarium Space Gallery	**Museum** Size: L	✔	www.liverpoolmuseums.org.uk
National Railway Museum	Discover the story of the train at the world's largest Railway Museum and have a great day out for all the family.	Railways Technology	**Museum** Size: L	✔	www.nrm.org.uk
National Space Centre	The National Space Centre is dedicated to space science and astronomy. Includes Space Theatre and a Challenger Learning Centre.	Space science Astronomy	**Science Centre** Size: L Opened: Jun 2001	✔	www.spacecentre.co.uk
National Stone Centre	Tells the Story of Stone—history, science, technology,	Extractive industry Earth science	**Other centre** Size: S	✔	www.nationalstonecentre.org.uk

	art, environment—in the heart of the Derbyshire Dales.		Opened: 1990		
The Natural History Museum	Major research and teaching collections in UK. Dedicated to our planet's life story, the Museum takes visitors on an unforgettable journey into Earth's past, present and future. The museum is home to life and earth science specimens comprising some 80 million items within five main collections: botany, entomology, mineralogy, paleontology and zoology.	Life and Earth Galleries Dinosaurs Mammals Creepy Crawlies Earth's Treasury	**Museum** Size: L Opened: The Darwin Centre opened in 2002	✔	www.nhm.ac.uk
Natural Science Centre	The centre has a planetarium, observatory, alternative energy displays and a large conservation area	Alternative energy Ecology Dinosaurs Geo Science Astronomy Space Science Conservation	**Science Centre** Size: S		www.naturalsciences.co.uk
Nature's World	Nature's World demonstrates practical ways to improve our quality of life and the environment. We illustrate the steps towards sustainability finishing with our futuristic eco-structure and hydroponicum (Future World).	Sustainability	**Other centre** Size: S Opened: Easter 2002		www.naturalworldcentre.co.uk
The Observatory Science Centre	Hands-on science centre set amongst the domes of the former Royal Observatory.	Science Space Astronomy	**Science Centre** 100+ exhibits Size: M Opened: 1995	✔	www.the-observatory.org
Our Dynamic Earth	A fantastic journey of discovery through the story of our planet. Face boiling lava, fly over glaciers and dive deep beneath the ocean in the experience of a lifetime.	Physical and biological processes that formed and continue to shape our dynamic Planet.	**Other centre** 12 galleries Size: L Opened: Jul 1999	✔	www.dynamicearth.co.uk
Paignton Zoo Environmental Park	Home to some of the world's most endangered plants and animals.	Animals Conservation	**Animals/Plants** Size: L		www.paigntonzoo.org.uk

The Palms Tropical Oasis	Set in a one-acre glasshouse and featuring exotic plants and wildlife, gardens and aquaria.	Animals Plants Conservation Environment	**Animals/Plants** Size: M		www.stapeleywg.com/palms.asp
Royal Air Force Museum, Cosford	An outstanding collection of aircraft and associated memorabilia.	Aviation Science	**Museum** Size: M		www.rafmuseum.org.uk
Royal Air Force Museum, London	From a total collection of well over two hundred aircraft, over a hundred full-size aircraft from all over the world are displayed under cover on the historic site of the original London Aerodrome.	Aviation Science	**Museum** 100+ exhibits Size: M		www.rafmuseum.org.uk
Royal Botanic Garden Edinburgh	The RBGE is dedicated to explaining and exploring the world of plants. Education is for all ages and stages, from casual visitors to botany students, and from children to senior citizens. Admission is free.	Plants Horticulture Botany	**Science Centre** Over 6% of all known plants—over 13,000 species exhibits Size: L	✔	www.rbge.org.uk
The Royal Botanic Gardens, Kew	The Gardens cover 300 acres and are home to themed gardens and plant collections, as well as a number of historic and 'working' buildings. The living collections are a resource for botanical science worldwide.	Plants from around the globe Science and horticulture Conservation of plants and habitats	**Animals/Plants** 1000s exhibits Exhibition area: 121,410 m^2 Size: XL	✔	www.rbgkew.org.uk
Royal Cornwall Museum, The Childrens House	A community based discovery centre, which explores the history and culture of Cornwall.		**Children's Museum** Size: S Opened: Summer 2002		www.royalcornwallmuseum.org.uk
Royal Museum	NMS holds a wealth of treasures built up over several centuries, encompassing archaeology, ethnology, decorative and applied arts, social history, science and technology, and the natural world.	Natural history Science and technology Art and design Ethnography Ancient cultures and world cultures	**Museum** 12,000 exhibits Exhibition area: 15,000 m2 Size: L	✔	www.nms.ac.uk
Royal Observatory	The Royal Observatory Visitor Centre aims to introduce the	Astronomy Space	**Other centre**	✔	www.roe.ac.uk/vc

Visitor Centre	general public and visiting groups to the fascinating world of modern astronomy and space research.		Size: S Opened: 1981		
Satrosphere Science Centre	Satrosphere is Scotland's original science centre. We encourage visitors to get 'hands on' with science through exploration and discovery. Fun-packed experiments, live shows and spectacular demonstrations bring science to life.	Science	**Science Centre** 50+ exhibits Exhibition area: 700 m2 Size: S Opened: 1990	✔	aberdeenscie ncecentre.org
Science Museum, London	The Science Museum is a major museum on Exhibition Road in South Kensington, London. The Science Museum now holds a collection of over 300,000 items, a recent addition is the IMAX 3D cinema showing science and nature documentaries	Science Technology Medicine	**Museum** Thousands of exhibits Size: L Opened: Wellcome Wing, 2000	✔	www.science museum.org. uk
Scottish Seabird Centre	Visitors control interactive cameras, sited on islands in the Firth of Forth to explore the fascinating world of seabirds, with thousands of puffins and gannets, and marine wildlife including seals and dolphins. The centre is now operating wildlife boat safaris around the islands of the Firth of Forth throughout the summer period.	Seabirds Marine environment Marine science	**Discovery Centre** Exhibition area: 340 m2 Size: S Opened: 2000	✔	www.seabird. org
Dundee Science Centre	Interactive Science Centre in Dundee. Also includes a 3D cinema, soft play area, internet café and shop. Roborealm, will give visitors the chance to interact with robots.	Senses Biology Science	**Science Centre** 60+ exhibits Exhibition area: 1000 m2 Size: M	✔	www.dundee sciencecentre .org.uk
Techniquest Science Discovery Centre	Techniquest is a Welsh science and discovery centre. Its aims are to engage people with science and to motivate them to learn more and they also address science-related areas such as maths, engineering and technology, with over 150 hands-on exhibits and fascinating shows in the	Biology Chemistry Earth and Space Electricity Energy Environment Forces Light and Colour	**Science Centre** 100+ exhibits Exhibition area: 1500 m2 Size: L Opened: 1986	✔	www.techniq uest.org

	Theatre and Planetarium make Techniquest a unique experience for visitors	Maths Humans			
Thinktank, Birmingham Science Museum at Millennium Point	Thinktank offers ten galleries of historical artefacts, modern interactives and futuristic facts. Visitors can explore everything from space travel to steam engines. In addition, the museum offers ten interactive galleries, supported by an extensive education programme, which includes workshops, planetarium shows and IMAX films.	Transport Industrial Revolution Local history Modern medicine	**Science Centre** Approx 260 exhibits Exhibition area: 7,500 m^2 Size: L Opened: Sep 2001	✔	www.thinktank.ac
Ulster Folk and Transport Museum	The award-winning galleries of the Transport Museum display Ireland's most comprehensive transport collections from horse drawn carts to Irish built motor cars, from the mighty steam locomotives, which graced our railways to the history of ship and aircraft building.	Transport Life and heritage	**Museum** Size: M	✔	nmni.com/home
Ulster Museum	Ulster Museum's displays feature material from the collections of Fine and Applied Art, Archaeology, Ethnography, Treasures from the Armada, Local History, Numismatics, Industrial Archaeology, Botany, Zoology and Geology.	Art History Natural sciences	**Museum** Exhibition area: 8,000 m^2 Size: L	✔	nmni.com/home
W5 - Interactive Discovery Centre	W5 is Ireland's only purpose-built science discovery centre. Located at Odyssey, Northern Ireland's Millennium Landmark. 140 interactive exhibits in five exhibition areas. The museum is previously known as INTECH, it is a hands-on, interactive, science and technology centre located in Winchester. The centre houses over 100 activities, all of which link in with the National Curriculum for schools.	STEM	**Science Centre** 140 exhibits Exhibition area: 3,600 m^2 Size: M Opened: Spring 2001	✔	www.w5online.co.uk

Winchester Science Centre	The museum is previously known as INTECH, it is a hands-on, interactive, science and technology centre located in Winchester. The centre houses over 100 activities, all of which link in with the National Curriculum for schools.	Science	**Science Centre** 40 exhibits Exhibition area: 300 m2 Size: S Opened: 1995 and 2002	✔	www.winchesterssciencecentre.org
World Museum Liverpool	World Museum Liverpool is the largest of the National Museums Liverpool venues. The fascinating and varied collections cover archaeology, ethnology and the natural and physical sciences.	Archaeology Natural sciences Physical sciences	**Museum** 5 exhibits Exhibition area: 100 m2 Size: M Opened: 1993	✔	www.liverpoolmuseums.org.uk/wml

Appendix 2 - The Selection of Two Case Studies

Name	**Summary**	**Themes**	**Type**	**Ecsite-uk membe**	**Website**
Magna Science Adventure Centre	Magna is set in Templeborough Steelworks in Rotherham. Inside you can explore the four elements of fire, air, earth and water and have fun firing giant water cannons, launching rockets, spinning in a gyroscopic chair, learning to fly, exploding rock faces and working real JCB's.	Fire Air Earth Water	**Science Centre** 120+ exhibits Size: L Opened: Apr 2001	✔	www.visitmagna.co.uk
Thinktank, Birmingham Science Museum at Millennium Point	Thinktank offers ten galleries of historical artefacts, modern interactives and futuristic facts. Visitors can explore everything from space travel to steam engines. In addition, the museum offers ten interactive galleries, supported by an extensive education programme, which includes workshops, planetarium shows and IMAX films.	Transport Industrial Revolution Local History Modern medicine Air and Space	**Science Centre** Approx 260 exhibits Exhibition area: 7,500 m^2 Size: L Opened: Sep 2001	✔	www.thinktank.ac

Name	Summary	Themes	Type	Exhibition Area	Exhibit Number
The Air Pavilion / The MAGNA	More than 15 metres overhead, high up in the rafters of Magna is the Air Pavilion. This giant suspended 'Zeppelin' is home to an array of exciting, hands-on, air-themed activities. Visitors can create stunning patterns with air cannons, witness a selection of humorous and disastrous attempts at early flight and explore how sound is made.	Air, Force, Early Flight	Hands-on Participatory Interactive	**553** m^2	20
The Futures Gallery / The THINKTANK	Explore the outer reaches of space, get to grips with innovative inventions and marvel at how medical advancements are saving lives. Head to Talking Point to consider scientists' predictions for the future. The Futures gallery brings to life how science, technology and medicine have a huge impact on the way we live - now and in the future. With interactive exhibits such as Create an Alien and RoboThespian, the Futures gallery aims to stimulate debate, explore scientific issues and question our place in the Universe.	Air and Space Exploration	Hands-on Participatory Interactive	**578** m^2	18

Appendix 3 - Case Study 1: Magna Science Adventure Centre

Figure 1. Bird's eye view of MAGNA.

Figure 2. Perspective view of MAGNA. (Source: Author)

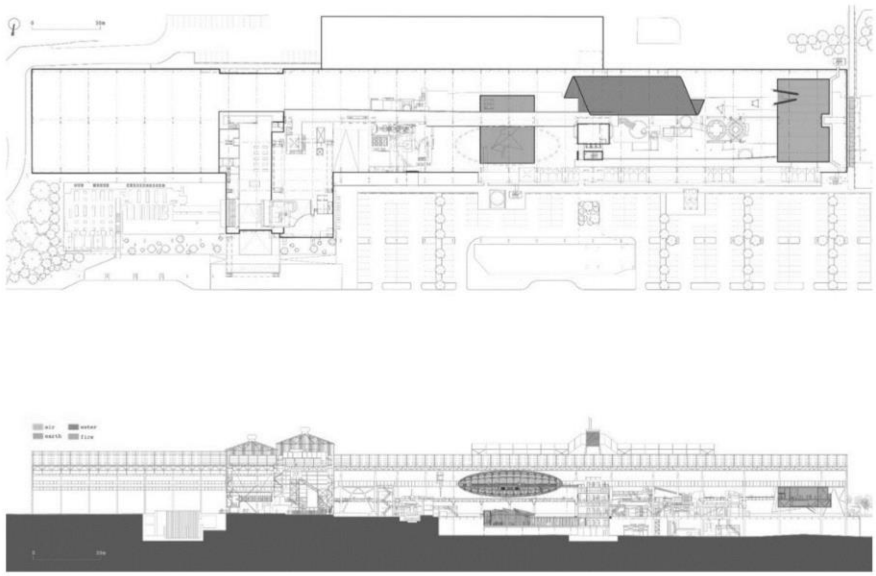


Figure 3. Plan and section drawing of MAGNA. (Source: Wilkinson Eyre Architects)

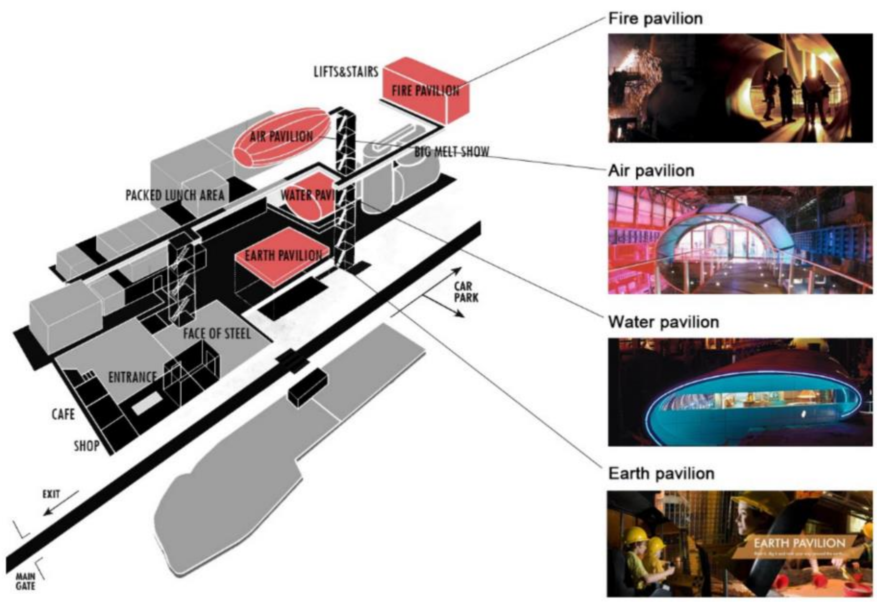


Figure 4. The location of four pavilions inside MAGNA. (Source: Author)

The Air Pavilion

The air pavilion is 44 metres long with a diameter of 16.7 meters at the centre that tapers to 5 metres at the ends. Two elliptical compression rings at each end, made of 114-millimetre diameter steel tubes, are joined by diagonal struts. Between these collars, longitudinal aluminium extrusions hold 11 ETFE cushions, with a maximum width of 4.8 meters, which extend the full length of the structure.

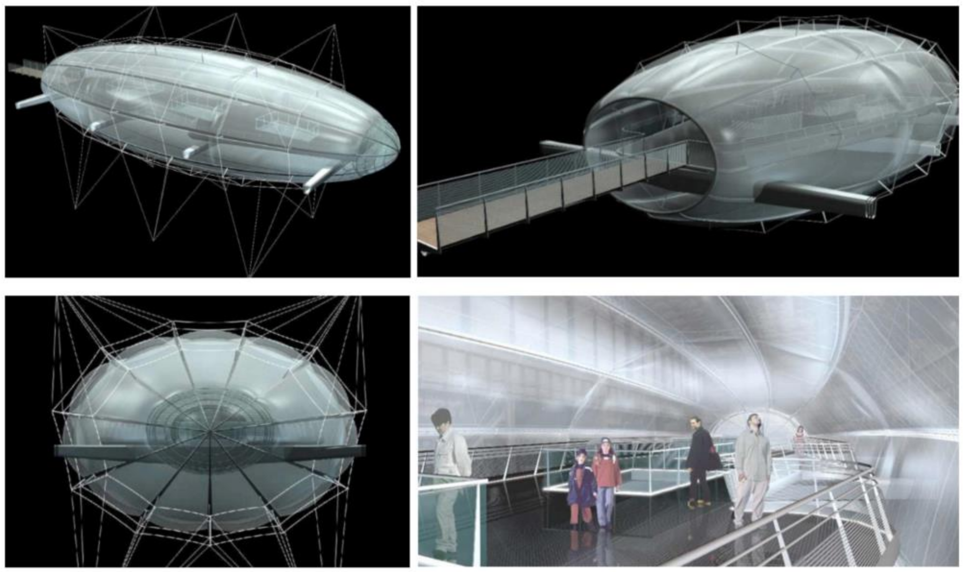


Figure 5. The structure model of the air pavilion. (Source: Wilkinson Eyre Architects)

The air pavilion is the most daring gallery on the top level. With 20 different interactive exhibits inside. Most of them are hand-on, interactive exhibits, with the exception of one or two that consisted of video presentations or in visual information only. Most exhibits were located against the perimeter boundary, or against structural elements, so visitors normally follow the loop around this oval-shaped pavilion. Because the text is in the same colour and font size it gives the impression that one has to read a lot to understand what is shown. This can lead to disinterest since many people do not spend a lot of time in front of one object. However, the pavilion is still a very educational, hands-on and engaging space for children and adults.

Figure 6. The photo taken inside the air pavilion. (Source: Photographed by Author)

1) Look at the air pavilion from the ground floor of MAGNA; 2) Entrance to the air pavilion

3) The air pavilion without a single visitor, taken on the 02nd of October 2015.

4) The air pavilion full of visitors. Thursday, 23rd of October, 2015 (School holidays)

5) The exhibit-Air Waves; 6) The exhibit-Air Hockey; 7) The exhibit-Spinning Chair

8) The exhibit-Air Cannon; 9) The exhibit-Good Vibration; 10) The exhibit-Cloud Ring

The interactive installations in the permanent exhibition differ from being up-to-date (like Air Hockey, Good Vibration) to almost old-fashioned (like Cloud Ring, Air Cannon, Spinning Chair…). The reason for this is the rapid development of new technologies. Based on the observations it is not necessarily important for the visitors that the used interactive technologies in an exhibition are totally up-to-date but what is important is that they work. Interactive modules which are out of order cause frustration and should clearly be avoided.

The following list shows detailed numbers about the analysis of the MAGNA's visitors. The observations took place on three different days. On each day, visitors were observed and counted for one hour. One of the three dates was during the school holidays. A difference between this day and an average weekday was only recognised in the number of visitors but not considerably in the constellation of families or in the age groups of children.

Total visitor numbers of all three days Total = 66 children + 51 adults (+ 9 individual adults)

Visitor numbers on Thursday, 02. October 2015

5X 1 adult 1 child (8, 10, 6, 14, 9)
2X 1 adult 2 children (6, 9; 9, 14)
0X 2 adults 1 child ()
1X 2 adults 2 children (4, 7)
1X 2 adults 3 children (3, 6, 8)
2X 1 adult
1X 2 adults
= 9 families + 3 groups of adults

Visitors of different age groups:

Age						In total
3-5				1	1	=2
6-8	2	1		1	1	=5
9-11	2	2			1	=5
12-14	1	1				=2

Visitor numbers on Thursday, 23. October (School holidays)

8X 1 adult 1 child (7, 10, 9, 5, 14, 8, 9, 6)
5X 1 adult 2 children (6, 6; 11, 6; 7, 3; 10, 10; 4, 5)
6X 2 adults 1 child (4, 6, 14, 4; 12; 6)
5X 2 adults 2 children (2, 7; 15, 9; 4, 6; 14, 7; 10, 6)
2X 2 adults 3 children (10, 7, 4; 11, 7, 5)
1X 1 adult
1X 2 adults
= 26 families + 2 groups of adults

Visitors of different age groups:

Age						In total
3-5	1	3	2	2	2	=2
6-8	3	4	2	4	2	=15
9-11	3	3		2	2	=10
12-14	1		2	2		=5

Visitor numbers on Wednesday, 12. November

2X 1 adult 1 child (9, 12)

3X 1 adult 2 children (5, 7; 4, 9, 8, 10)

1X 2 adults 1 child (7)

2X 2 adults 2 children (3, 5; 5, 8)

0X 2 adults 3 children ()

0X 1 adult

1X 2 adults

= 8 families + 1 group of adults

Young visitors of different age groups:

Age						In total
3-5			2		3	=5
6-8			2	1	1	=4
9-11	1	2				=3
12-14	1					=1

Appendix 3.1 Observational analysis

The following research is based on field research and observation analysis, which including general field observation inside the museum (Appendix A.1), an analysis of public comments on ranking websites for leisure experience and learning activities (Appendix A.2) and on semi-structured interviews with visitors of MAGNA (Appendix A.3).

- The field observations were carried out over a period of two months during (October-November, 2015) and include monitoring visitors and their interaction with the exhibition as well as studying the facilities, spatial qualities and architectural factors of the MAGNA site.
- The website analysis is adopted as the primary source of this study; main conclusions were drawn using Tripadvisor.UK as the main source. This online service had the most reviews compared to other ranking websites, there are 775 ratings of visitors were submitted until 1st of February 2017, so most quotes are derived from this website (Appendix A.2). On Tripadvisor, 165 people had rated MAGNA with an average of 3.5 out of 5 stars (updated on February 2017). These kinds of websites give visitors the chance to rate a public institution and to leave comments about their experiences. MAGNA's overall rating is rather high but some negative comments point out essential problems, which contribute to the visitor's dissatisfaction.
- Semi-structured interviews were conducted with ten group of family from the MAGNA after their visit. The interviewed visitors included one couple without children, four families with each two adults and two children, three families with each two adults and one child and two families with each one adult and one child.

As it is mentioned before, about sixty percent of the MAGNA's visitors are children. Since children rarely come on their own to visit an exhibition, it can be assumed that the main group of visitors are families[1]. (Although school groups are also a target group of MAGNA, these will not be the focus for the research since we know the groups rather come to the museum for guided and prepared workshops than for visiting the exhibition.) To define the constellation of an average family visiting MAGNA, an observational research was conducted, each observation took about one hour in which families and other visitors in the permanent exhibition were counted. The age of children were pooled in age groups. In total 43 families and 9 adults, of which three were visiting on their own, were identified (Appendix A.1).

[1] Depending on various factors the definition of a family can vary widely. In this project a family is considered a social group with at least one child and one adult being the legal guardian, usually parents and their children or grandparents and their grandchildren.

Total visitor numbers of all three days Total = 66 children + 51 adults (+ 9 individual adults), as it is shown in **Figure 3.1-1.**

3-5	16	approximately 24,24 %
6-8	24	approximately 36,36 %
9-11	18	approximately 27,27 %
12-14	8	approximately 12,12%

15X 1 adult 1 child	approximately 34,88 %
10X 1 adult 2 children	approximately 23,26 %
7X 2 adults 1 child	approximately 16,28 %
8X 2 adults 2 children	approximately 18,60 %
3X 2 adults 3 children	approximately 6,98 %
3X 1 adult	
3X 2 adults	

Fig 3.3-1. Total visitor numbers of all three days Total = 66 children + 51 adults (+ 9 individual adults)

MAGNA's current focus on children's age groups was stated as being between eight and fourteen (Beck, 2008), whereas the investigation of the visitors revealed that many children are also younger. Over sixty percent of the observed children were eight or younger and only about twelve percent were estimated as being twelve or older which matches with the overall impression gained during the entire research phase. As it is shown in, the average composition of a family during the research was one or two children accompanied by one adult (approximately 58%) which is similar to the statistics about the average family who consists of either one (40%) or two (42%) children and one or two adults.

While a couple of years of age difference do not matter for adults, it makes a significant difference for children. That is the main reason of separating families into these three groups. Especially at a young age, the development of a child in one year can be enormous. Not only do the motor skills improve by every year but also the capability of reading and understanding instructions or the ability to imagine certain situations or processes. Since the focus of MAGNA is rather on older children, also the exhibition and the installations are designed for such a target group, which results in younger children being over challenged. This is backed up by visitor comments like "My 6-year-old boy found the exhibition a bit too advanced" and "I went with my grandchildren aged 8 and 13, both of them enjoyed it although I felt it was aimed more for the older one. But the younger brother was still loving it and wants to go back when a bit older and do the bigger challenges." One of the arising problems is that it does not only affect the child but the entire family.

Young children are not able to interact with the exhibition by themselves and need help of an adult. During the research, it was frequently observed that this results in parents rather helping their children to interact than getting involved in the subject. However, it gets especially challenging when one adult is accompanied by one younger child and one older child. In that case, the grown-up needs to take care of the younger one while the older one has to be autonomous.

The current target group of MAGNA is not identical with the average group visiting the museum. Children younger than eight are often over challenged and a shortage of suitable interactive modules for them is affecting the family experience. There is a need to broaden possibilities for suiting interactions also for younger children. Therefore, in the field survey, observed children is also divided into different age groups as **Figure 3.3-2**. Moreover, it is realised that among a social group, each member has a certain role and is next to being a part of the group also an individual having specific opinions, demands and wishes. This is even more pronounced in a family. The interaction between adults and their children is crucial for an experience together but the trigger to get one's attention or interest differs to a larger extent. To be able to consider the demands for both target groups equally, the preferences for children and adults are first discussed separately and then regarded in the family interaction.

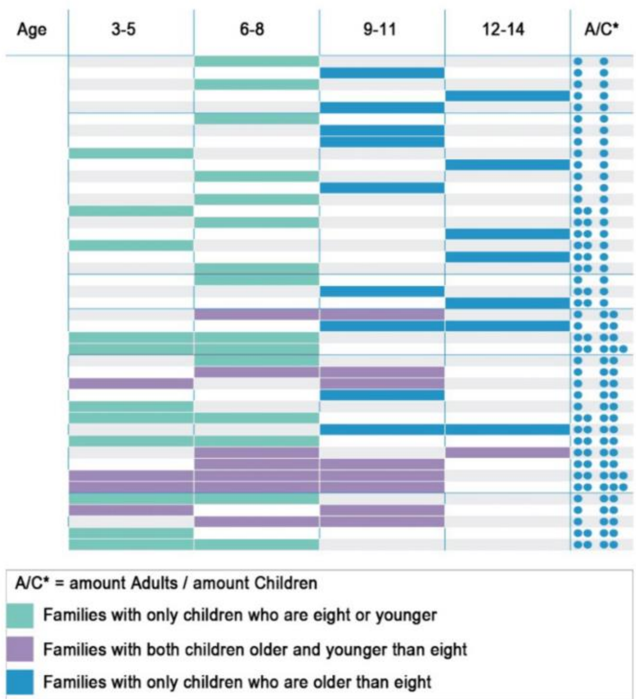


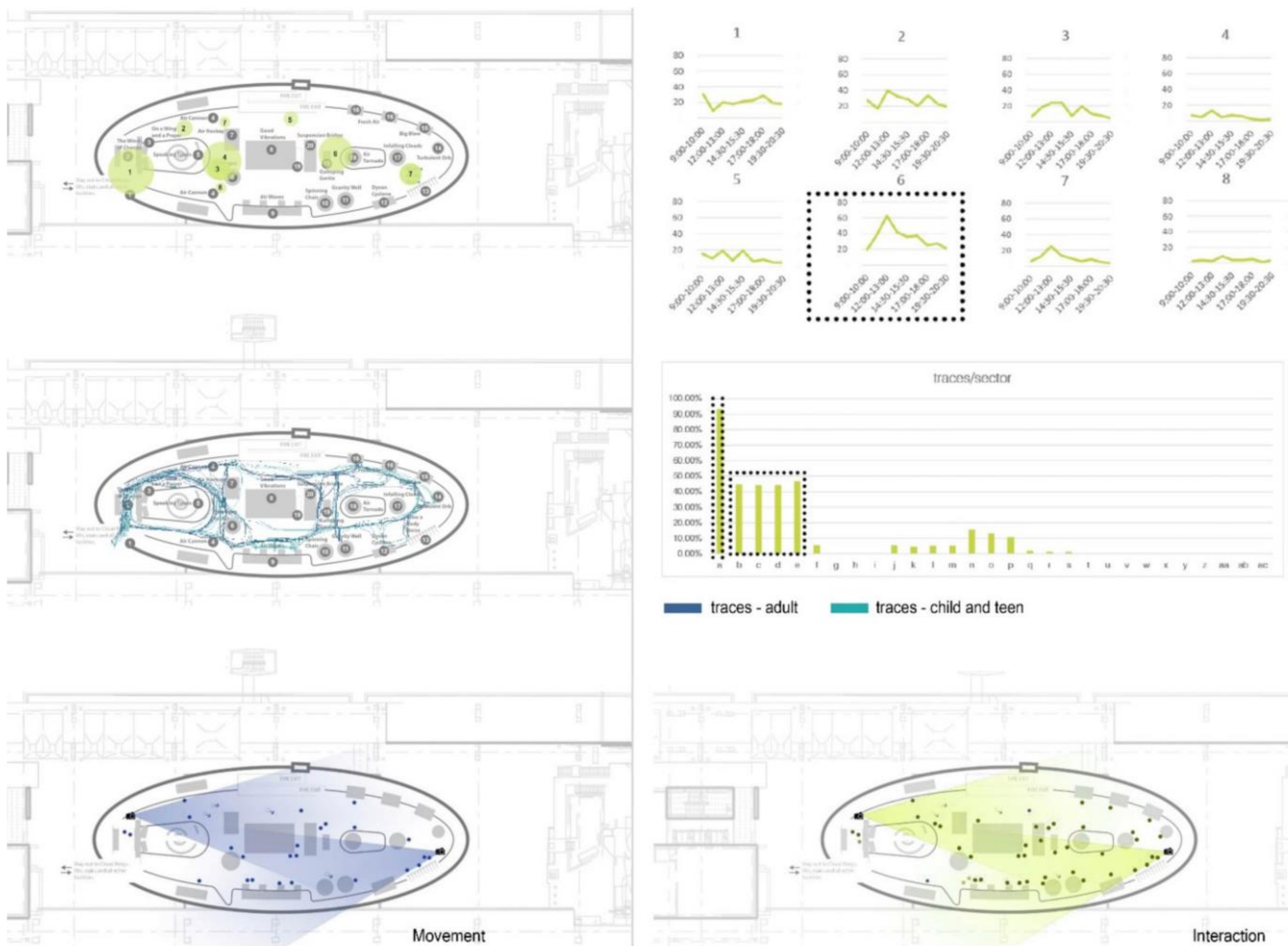
Fig 3.3-2. The age groups of the observed children are indicated in this figure: The colour green shows all families who had only children being eight or younger; Blue indicates families with all children being older than eight; Purple visualises the families who had at least one child being eight or younger as well as one child being older and thus in the initially identified target group of Magna.

The number of dots in the column 'A/C' indicate the amount of adults and children.

The detailed observation inside the air pavilion

There were several methods adopted for the field observation, as the gate method, people following/ movement traces and static snapshots. As results shown in Figure 3.3-3.

Fig 3.3-3. The site observation inside the pavilion.



1
2
3
4
5
6
7
8
9:00-10:00
12:00-13:00
14:30-15:30
17:00-18:00
19:30-20:30
traces/sector
traces - adult
traces - child and teen
Movement
Interaction

Appendix 3.2 List of public comments from the TripAdvisor

This appendix discloses all public comments from ranking websites, which were considered important. Most reviews are from the online platform TripAdvisor and unless otherwise stated, quotes are derived from this source [tripadvisor.co.uk, 2017]. The remarks are divided in positive and negative comments and grouped similar to the categorisations in the summarised findings about MAGNA's exhibition in the case study chapter. On Tripadvisor UK, 775 ratings of visitors were submitted. (Until 1st February 2017)

The average of 3.5 out of 5 stars results from 165 visitors assessing the experience with five stars (excellent); 237 visitors with four stars (very good); 157 visitors with three starts (satisfying); 116 visitors with two starts (deficient) and 98 visitors with one star (insufficient). On the other website, the comments were similar, but not many people expressed their feeling about the visit experience.

A selection of the main positive comments:

Hand-on Activities

- "The children and we loved all the interactive hands on activities and they are already asking to return. They were less interested in the steelworks but I felt it all added to the feeling of the place."
- "There are lots of hands on activities for the children and adults to explore through themed areas such as Water, Earth, Wind and Fire. You need at least 2 hours to have a good look around although you could easily spend a day here."
- "...turning an unused steel recycling works into a fully interactive, hands on attraction is astounding."
- "Lots of hands on exhibits, very appealing to a 7-year-old boy."
- "There's lots of hands on activities for kids (our 3 and 5 yr old boys enjoyed each section, particularly Water and Earth) and interesting for adults as well."
- "The way of exposing is very lively with a lot of interactive plays. This makes it fun for children as well. As a result of this it might be a bit too busy."
- "The museum had plenty of hidden nooks and crannies to explore with plenty of hands on activities."
- "It is targeted at a young audience with lots of hands-on exhibits"
- "What an amazing place. It is huge inside and easy to get lost. The history of the steel mill is everywhere and videos, hands on exhibits, demonstrations and special effects make it very entertaining and educational."

Family Appreciation

- "A lot of interactive, interesting things for our whole family group, aged from 3 years to golden oldies. Really fun for all, as well as very informative for older children. Educational in an entertaining way."
- "Really good family day out very interesting place like how pay once and can go again all year for free my autistic son loves it here"
- "My wife and I found that the displays were good for both kids and adults."
- "What can I say apart from loving this day out with the family, Magna is an exciting place with lots to do for everyone."
- "Interesting museum which would appeal to families with young-ish children."
- "A museum especially for children, but adults also like it."
- "Great for adults and children alike."
- "This is a really good day trip for all the family - whether you come to simply have some fun but also educational. There are four elements to the science centre, the fire & air are extremely good. My advice would be to leave the "water" until last - in case you finish up with some wet young people!"
- "Magna is an amazing experience for young people to learn about Sheffield's place in the world of making! Also great for the rest of the family to relive some 'olden times' and past experiences."
- "This is a museum that is not huge but each floor has its appeal for children from about 8 years…"
- "It is targeted at a young audience with lots of hands-on exhibits, but it is also great for an adult."
- "The oldest (12) didn't need any help, the younger ones did (7), but that was no punishment."
- "A great place to visit for the kids and the family. Has demonstration and the history of the old Sheffield Steel works as well as other science projects and also a great play area for children outside. In the play area, there are water jets for children to have water fights, so should the summers be hot and long, it's busy. Inside, there often from time to time have shown or other events."
- "My eldest absolutely loved the fire exhibition and the littlest LOVED the water. When we had finished in the attraction we went outside to the outdoor play area and I must say how fantastic it was! It is honestly the best play area we have been in and we would come back just for that reason. Me and my partner had more fun than the children!"
- "Very educational, very hands on, very engaging for children and adults."

Architectural Space Quality

- "I personally loved the space - huge old industrial space very cleverly lit and lots of interactive displays."
- "This decommissioned Steelworks is an awe-inspiring building. Very cleverly transformed into a visitor centre. Leaving huge spaces as existing machinery and then adding tonnes of atmosphere and inspiration."
- "I have to point out that the kids had a fantastic time, and were genuinely excited about the massive dark, echo-y space and the history of the steel works."
- "Overall I think it was interesting to go once, I'm not sure I'd go again unless they added exhibits. They need to check everything works and it's a good opportunity to see inside an impressively vast spatial structure with a proud history."
- "Visually it is also interesting, quite artistic and stimulating. It's an old steel works which is absolutely HUGE, awe inspiring to realise it was this big."

A selection of the main negative comments:

Technology Out of Order

- "Some exhibits also didn't appear to work, but again no staff to explain what to do or how things work."
- "... a little frustrated a lot did not work properly when interaction was wanted. There was nobody around to tell whether it was broken or why it was not working."
- "... some of the kiosks have been a little over used and aren't working properly."
- "First of all, a lot of animations were broken or did not work properly."
- "LOTS of the equipment/activities don't work. It's such a shame, as there's nothing more frustrating. I feel the entire place needs troubleshooting."
- "Pity some of the displays are broken - these should be a priority to fix."
- "We paid £50ish to go in, yet only 60% of the interactive displays and experiments actually worked. I lost count of the amount of times I was asked 'What is this one supposed to do, Mum?' for me to reply 'I think it's broken'. Such a shame, as if it were all working I'm sure the place would have been so much busier. We were there during the school summer holidays and there was hardly anyone there! The kids loved the fabulous outdoor play area, which I noted was lottery funded. Shame the lottery couldn't had thrown come cash at Magna itself as it is an amazing space full of interesting things - if only they worked."

- "Very disappointed overall, it's seems a million miles from what it was when I went as a little girl, although that was probably 15 years ago, but surely it should have had a vast improvement and not gone the other way?"

Vast but Empty Space

- "Disappointingly dark and empty. The space is vast, nay, gigantic, and the explanatory boards and videos are helpful. However, the machinery that is still there is not really used to its full potential.
- "The whole purpose of this museum (if one could call it that) is one big mystery."
- There's a lot of empty spaces that could be filled in with new exhibits."
- "Furthermore, I could not say what the common theme of the museum was. The designs were too diverse."
- "What a missed chance. No structure, no suggestions for explorations."
- "We only spent an hour and a half there within the attraction. While I appreciate, it is an old building and the attraction has to be done around its structure, I found the grounds huge, but the attraction barely there."
- "The different sections of the Exploratorium are set within this massive, eerie, cold, dark structure and there is quite a bit of walking to be done. I am quite sure that some people simply don't 'get' this aspect of the experience. In a way, this lack of appreciation of scale could exaggerate any feelings that there is 'not much here'."
- "The place is vast! It's dark and noisy too. Now my boy loved it but it may scare some children."
- "The atmosphere in the vast building is suitably industrial and a little spooky; the scale is quite intimidating."

Orientation / Wayfinding System

- "When you enter the place, you go through a great big black hall and there are various information points where it's so dark you can't read what's going on and there's a heck of a lot of walking while you keep wondering what you're supposed to be doing. This can really dampen a child's enthusiasm, not to mention an adult's. You begin to wonder if you're ever going to get to anything that is worth doing! And we really wanted to find out more about steel making but we never found anything that explained it from beginning to end in a clear way."
- "I think this place really, really needs some kind of defined introduction area which tells you what you can expect, what the building is, what steelmaking is, and generally which welcomes you in. I liked, however, the dramatic feeling and sense of space, it's just that it needs to be organised better."

- "The building is vast. The guide, although well-informed, spoke quite softly so it was often difficult to hear him above the 'atmospheric' noise. There is far too much background noise, induced to represent the machinery but really quite unnecessary."

Installations (exhibition) too Challenging for younger children

- "My 6-year-old found it a bit too advanced though."
- "It is important that a child can read to get the most out of the permanent displays."
- "The exhibits are fairly limited, and the labelling was missing in several cases."
- "A lot of objects without explanation. Even though the installations look expensive it is a mess: many screens with buttons and so on but way too little explanation."
- "…. kids were just pressing buttons and not knowing what was going on or having any fun or even knowing whether the things were actually working or not."
- "It caters for everything from training centre to school visits where children can try different science activities out. There is a large play area here for the younger ones."
- "Magna is most suited for primary school aged children, and there are lots of opportunities for learning through play."
- "I went with my grandchildren aged 8 and 13; both of them enjoyed it although I felt it was aimed more for the older one. But the younger brother was still loving it and wants to go back when a bit older and do the bigger challenges."

References:

Tripadvisor.uk (2017) Magna Science Adventure Centre

https://www.tripadvisor.co.uk/Attraction_Review-g190734-d284962-Reviews Magna_Science_Adventure_Centre-Rotherham_South_Yorkshire_England.html

[Accessed 1st Feb. 2017].

Appendix 3.3 Semi-structured interviews with visitors

During the research phase about the MAGNA, visitors were interviewed to include their personal opinions and experiences in the analysis. People were approached when they were about to go downstairs and thus leave the exhibition area. In the following section answers of the interviewees are grouped in the categories used in MAGNA's analysis in the chapter of case studies. The categories are '**The current exhibition and the installations**'; '**the orientation system**'; '**routing and structure**' and '**informal learning experience**'. To create a comfortable atmosphere, questions were prepared to make sure that main areas were covered during the conversations. However, these questions were rather a framework and people were asked to talk about their preferences and experiences freely.

Questions for the interview framework

- Have you been to the Magna Science Adventure Centre before?
- What was your reason to come to the MAGNA today?
- How did you like your visit?
- What did you like most about the MAGNA and why?
- Is there anything you don't like about this museum?
- Have you noticed the orientation system of the museum?
- How would you describe the way you visited those exhibitions inside, which exhibition you enjoyed the most?
- What do you think was the exhibition inside Air Pavilion about? Can you point out any specific themes for this pavilion?
- Can you point out which part/exhibit you like the best inside the Air Pavilion exhibition?
- Would you say that you have learned something during your visit? What was that?
- Was the level of complexity suiting for each member of your Children/ family?

Appendix 4 - Case Study 2: Thinktank, Birmingham Science Museum

Figure 1. Bird's eye view of the THINKTANK. (Source: Google Map)

Figure 2. Perspective view of the THINKTANK. (Source: Author)

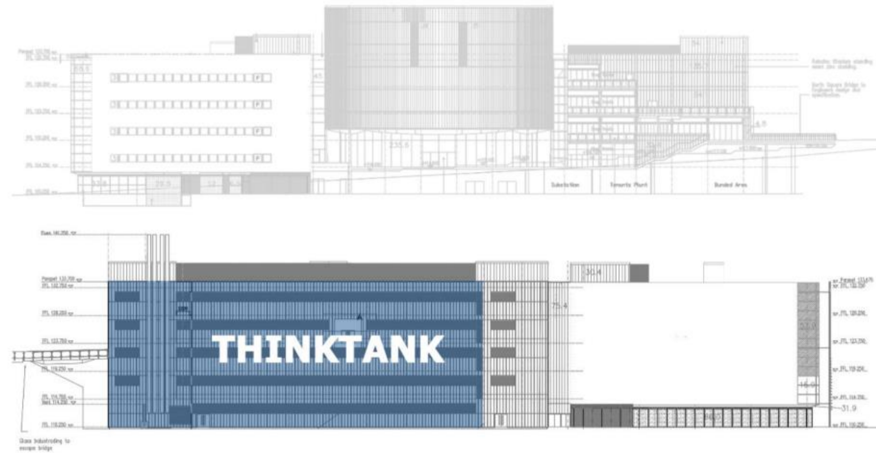


Figure 3. Elevation drawing of the THINKTANK. (Source: Grimshaw Architects.)

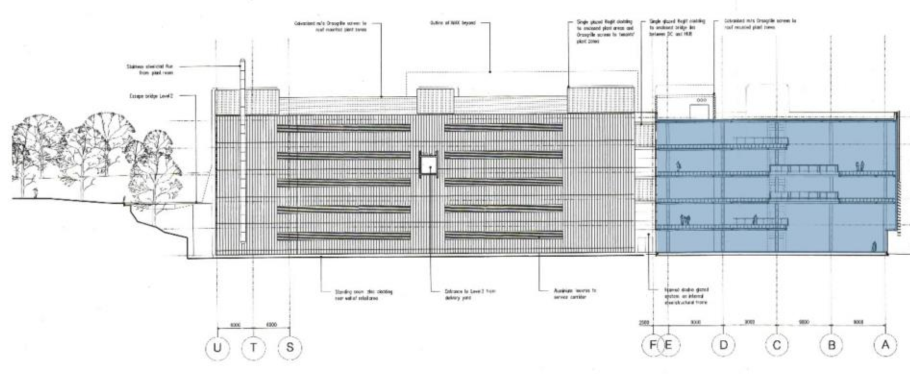


Figure 4. The section drawing of the THINKTANK. (Source: Grimshaw Architects.)

The Futures Gallery

The focus of the exhibition is on the concepts common to all space flight and so uses the narrative of a possible future space mission, as opposed to any particular historic mission, as the framework to communicate these ideas. The medium of the video game on those interactive tables or other interfaces, as exemplified here by the system of games and simulations that make up the score of the exhibition – Future Horizon, speaks powerfully to children and adults.

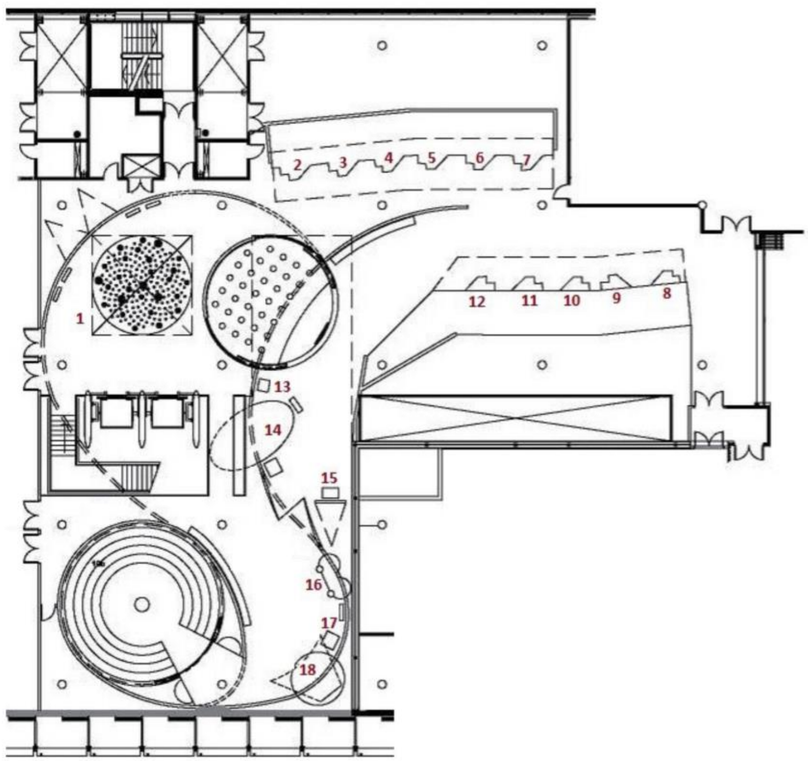


Fig 5. Exhibition floor plan of the futures gallery (**Source:** HKD Studio, edited by author)

Visitors learn about the challenges are the excitement of spaceflight in this exhibition, then apply that knowledge as they fly the spaceship, pilot the landers and drive the rover, in a thrilling narrative adventure to Earth orbit, the Moon and Mars. Those advantage technologies also help to support collaborative learning and co-construction of knowledge.

Appendix 4.1 Observational analysis

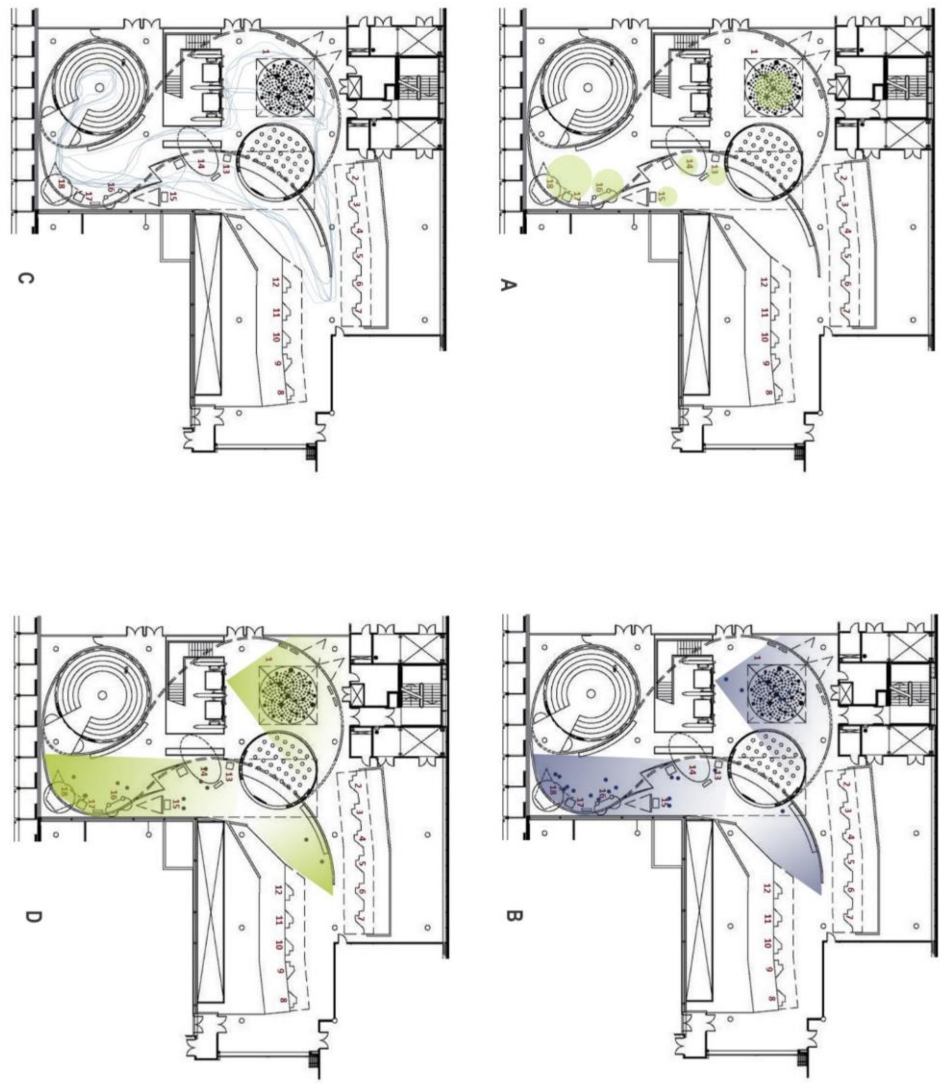


Fig 4.1-1. The site observation inside the Futures Gallery.

Appendix 4.2 List of public comments from the TripAdvisor

Most outstanding answers, grouped in the before mentioned categories

The Current Exhibition and the Installations

- "Many of the exhibits on the lower floors haven't changed since it opened. Nor gave most of the upper floor interactive items. Several are showing their age and not working. Planetarium was good if show was a little short. The science garden was new to me and quite good. It can all be seen in a couple of hours so not great value for money. If you're taking someone for their first visit it's good but not worthwhile revisiting otherwise."
- "Thinktank has some nice exhibits, but after an hour my 9 year old was getting bored, went to a couple of show times elephant story-telling not very good , and 1 where the kids get to learn about dinosaurs and monsters where they can touch , tusks teeth, bones etc. We enjoyed the outside science park. But still there was a lot of exhibits where nothing worked when pressing the buttons or was out of order.
- "This isn't a cheap day out (£41 for a family ticket - but lots of Internet voucher discounts available, so no need for anyone to pay full price), so we were slightly surprised that there were no scientific demonstrations, no staff explaining things, and everything was "self-guided". There was no leaflet with some "must-sees", and no recommendations for particular age groups. A lot of the material is aimed at the pre-school end of the market (e.g.: a life size pedestrian crossing... Is that really helping anyone with science?!) But the hands-on exhibits were either (a) not working, or (b) working but largely devoid of scientific explanation. There has too much emphasis on making science "fun" and not enough on helping people access an actual understanding of it.

  If you want your children to actually gain something from visiting it, you yourself need to be prepared to explain how different steam engines, pulleys, pressure, friction etc work.

  Most adults weren't explaining things to their children, and were just leaving them to get on with it. Consequently the place was filled with children flitting from one thing to the next, and treating the place as full of rather slow toys. There is some great potential here - it just needs a team from one of the better London museums to be parachuted in for 6 months and give it some direction."
- "There are hands on things for the children to play and learn with, it is great that you can try out so much." (Family without children)

- "We had an ok day here but it was really a place for kids, quite a few of the displays were either broken or sticky to touch."

The Orientation System

- "We took our two year old daughter today. First of all - the car parking is behind Millenium Point and isn't sign posted - we parked on a side street. Outside of Millenium Point would be impressive but it's mostly still a building site. The science museum is fairly small. There's four floors - but one was closed. We headed to the planetarium. Myself I liked the show - but it was all rather basic and lacking in science (more of this later). The presenter was excellent though and obviously loved astronomy. We passed the robots on the same floor - it looked impressive but really amounted to pressing a button and watching very limited interaction. Maybe 20 years ago, this might impress but even my 2-year-old plays with an iPad and is used to something a little bit more engaging. The second floor was "present day" - this amounted to a large space of ... dressing up costumes, wooden cars, a water feature (I liked - my daughter was bored quickly) and pretend cafe, garage and doctors surgery. More importantly, WHERE WAS THE SCIENCE? Young kids like to dress up but my daughter does all of this at nursery (and more) and if you go to a science exhibition (especially one called "think" tank) you'd expect something which inspired kids into finding out more about science ... There was a natural history section - god it was boring and completely ignored.

  I wished this wasn't a negative review and all the kids seemed to have fun but really what a boring and uninspired approach to teaching kids about the fascinating world of science. One the way home I thought of all the things I'd have put in the museum - lasers, holograms, maybe an onsite chemistry demonstration, some real natural history (i.e. things they can actually touch) ... "I actually only noticed it when I looked for the toilet. We just walked through the exhibition via all those stairs."
- Today I was visiting with my 7 and 5 year old children. The first problem was finding it - there appear to be no signage outside, and having found the Millennium Point building, we could see the exhibits inside - but couldn't see an entrance. Eventually we found the way in by following somebody who obviously knew where they were going. What a palaver to have to go up to the second floor to get in, only to descend to ground level once inside. It seems that whoever designed the place had deliberately gone out of their way to prevent people finding the way in. Inside, I noted signs saying there was no direct access to the Science Park outside in order to maintain the temperature because of the exhibits; I still can't see why it doesn't have a ground floor entrance from the Millennium Point foyer though.

Routing and Structure

- "The attraction is divided into different sections with a planned route through them. There are video screens dotted around where you should be able to learn about the section that you are in but sadly on our visit the majority were out of order, those that were working the sound seemed to be out of sync with the video." (Family with children)
- "I think the exhibition is a bit chaotic. Some topics are really interesting but then there is not much about it." (Family without children)
- "I like coming here with the children but I never know what each exhibit is about. But the kids have fun and can see different things and we do something together." (Family with children)

Informal Learning Experience

- "Well worth a visit! Has a lot to learn for young children and in this case a young adult. A lot of the displays are sensory would full recommend!"
- "We've taken our 6- and 8- year olds here at least 8-10 times in the last six months; they can't get enough. They love the interactive displays, the planetarium shows, the crafts activities, the cafeteria, and of course, the outdoor play areas. I'm not doing the math right now, but I think that if you go even twice with a family of four, you get your money's worth if you buy the membership. We love Thinktank!"
- "I'd never visited before. However when asked what my 6 and 8 year old wanted to do it was settled. Perfect for a family day out. The planetarium was good; however, it's understandable that the museum wants to update the technology used. The 4 children in our party all enjoyed the imagination section with the role play areas."
- "Sometimes the labels were missing which was frustrating because I would have liked to know more." (Family with children)
- "We visited today and had a great time, all the exhibits are interactive and kept our girls (7 &3) entertained and interested." (Family with children)
- Myself and my partner popped in here and were very impressed (with the odd exception) - the museum is on several floors and practically every exhibit is hands on, which is great and makes it fun to walk round, both for adults and children. Some of the exhibits didn't work properly (although these were in the minority). However, particularly given the bonus of outside exhibits, this was a great experience and we will definitely be back." (Family without children)

- "Many things were too complex for our four-year-old son. But my husband and I just split up so he could go through the exhibition with the older one and I took care of the younger." (Family with children)
- "It's suitable for all ages, I have kids aged 2, 8 and 15 and all found something of interest there. Then there is a large outdoor play area which is great and water play area which you can stay in as long as you like." (Family with children)

Augmented Spatial Quality

- "The interior is very dark for no reason that I could tell and it was difficult to read the few placards that were on display as they were dimly lit and positioned at a height that meant you had to crane your neck." (Family without children)
- "The displays are the same every year nothing new is added or changed so if you visit often it can get boring. Which is a pity as they do have a vast space to expand displays." (Family with children)
- "So, I think this place really, really needs some kind of defined introduction area which tells you what you can expect, what the building is, what steelmaking is, and generally which welcomes you in. I liked, however, the dramatic feeling and sense of space, it's just that it needs to be organised better." (Family without children)
- "I had high hopes for this, but the huge space is wasted with much of the space being empty or providing very poor historical data on iron smelting and the building's original purpose. The displays where small and hard to hear. The building is freezing, and everything is so dark and dull." (Family without children)
- "It did seem to me that within the huge area of the factory most of the space was walkways and the old equipment which had descriptions and information throughout but the bit we paid for which was the hands-on science experience was really average and only a small part of the area." (Family with children)
- "Great day out for all the family easy to get to by car lots to see an do as you walk around interactive for the kids with a space section so you can learn about the planets most relaxing, an there's somewhere to eat as well so it's a visit you'll enjoy if you're interested in things from the past." (Family with children)
- I have visited the think tank in Birmingham as a couple, as a teacher with 90 children and as a parent of a toddler. Each time it has been an enjoyable experience and I have seen a different side of what this venue can offer. As someone with an interest in Science, I find this to be a great day out with lots of different options dependant on your requirements. There are many curriculum links if you have school age children and makes a great school trip, as they also offer workshops. If you have younger children, level 2 where you enter is completely interactive and is a great space for toddlers and pre-schoolers to role play."

Appendix 4.3 Semi-structured interviews with visitors

Semi-structured Interviews with Visitors in THINKTANK

During the research phase about the THINKTNAK, visitors were interviewed to include their personal opinions and experiences in the analysis. People were approached when they were about to go downstairs and thus leave the exhibition area. In the following section answers of the interviewees are grouped in the categories used the analysis in the chapter of case studies. The categories are '**The current exhibition and the installations**'; '**the orientation system**'; '**routing and structure**' and '**informal learning experience**'. To create a comfortable atmosphere, questions were prepared to make sure that main areas were covered during the conversations. However, these questions were rather a framework and people were asked to talk about their preferences and experiences freely.

Questions for the interview framework

- Have you been to the Thinktank, Birmingham Science Museum before?
- What was your reason to come to the THINKTANK today?
- How did you like your visit?
- What did you like most about the THINKTANK and why?
- Is there anything you don't like about this museum?
- Have you noticed the orientation system of the museum?
- How would you describe the way you visited those exhibitions inside, which exhibition you enjoyed the most?
- What do you think was the *Future Horizon* exhibition about? Can you point out any specific themes inside?
- Can you point out which part/exhibit you like the best inside the Future Horizon exhibition?
- Would you say that you have learned something during your visit? What was that?
- Was the level of complexity suiting for each member of your Children/ family?

Appendix 5 - Design-based Research: Hong Kong Space Museum

1. **The Proposed Work Plan**

This project will require a large proportion of unique exhibits and, while some ready-made exhibits may be purchased from other institutions they are of a general nature, and we are very interested in developing exhibits that introduce some of the more abstract concepts of astronomy and physics in fun and interactive ways. While many companies can deliver interior design and graphic design solutions, we focus our programme of work around delivering unique working exhibits and our work plan reflects this from the outset.

Task 1: Conceptual Design

(3 months)

Our focus in this stage is to establish the story content and the means that we are to tell that story, favouring interactive exhibits and games over explanatory texts. We will begin with an intensive workshop session in Hong Kong with the aim of fully understanding the brief and the requirements of the Museum and establishing the key exhibits for each area. These will be developed with specialist subject consultants and represented to the Museum in month 2.

An important component of our proposal will be to integrate game play into the museum and extend those ideas out into the wider social network via the internet. These concepts will be developed at this stage and tested with a variety of audiences both online (via a teaser game?) and in the museum. The storyline and concepts will be tested with a local audience through a consultation meeting with selected groups to confirm that the science and content is accessible to our target audience. An online data directory will be established for the maintenance of all exhibit designs and records that will be made accessible to all parties using Autodesk 'Buzzsaw' or similar that will enable access to drawings and documents on a variety of devices. A final presentation of all key exhibits, storyline and space planning will be presented and reviewed in Hong Kong in month 3.

Task 2: Preliminary Design

(5 months)

During this stage our tasks will divide into further content and exhibit development and to confirming space planning and the practical issues of production. Where existing exhibits are identified for purchase, they will be reviewed and vetted for accuracy and relevance, if necessary visiting the manufacturers. New exhibits will be developed in further detail and those that require prototyping will be identified and manufacturers sought. This is also an important time to establish budgets and confirm that the proposed designs will be affordable. Adjustments and revisions will be made until the budget is met. We will consult with our local partners in Hong Kong to confirm that building code and city regulations are also adhered to in the general arrangements of the galleries.

Presentations and review meetings will take place every eight weeks in this period with weekly telephone or video conferences to keep everyone up to date. Our intention is always to have all parties in full agreement of the design by the time that we make a final presentation proposal for sign off at the end of the stage

Task 3: Final Design

(4 months)

At an early stage in this final stage of design we will test the design with selected fabricators to confirm our budget allocations and make adjustments as necessary so that the design proceeds to budget. Another important test will be to conduct evaluation meetings with key stakeholders, such as a local astronomy society and school or university, to confirm the accessibility of the concepts and exhibits. This will be done with models and drawings or with prototypes if available. To be scheduled at the start of this phase. As the greater level of detail will need regular decisions from the museum and specialist consultants, we will meet every six weeks to keep the project moving and continue with weekly teleconferences.

Preliminary graphic design styles and methods will be employed to layout key design panels and a detailed illustrations directory will be established for the commissioning of original artwork. Sketches and finished artwork will be stored online for easy access and review. Outline script will establish main headings and any key titles or copy that will need to be incorporated into artwork. Translations of key text will be completed and used in artwork layouts to confirm design practicality. Final detail drawings, exhibit descriptions and outline scripts will be developed in parallel for delivery at the end of July 2016.

Tender and Award

(12 months)

During this period the Museum will prepare the tenders in accordance with Government regulation and conduct the tender and award process. We will review all tenders and prepare a tender report for use by the museum and, if required, attend interviews and negotiation meetings with selected contractors.

Task 4: Fabrication and Production

(8 months)

This phase will start with detailed meetings with the appointed fabricator to ensure that all details are fully understood and that an agreed working method is established for approvals, revisions and detailed development. Depending on the location of the fabricator's works, meetings will be held every 8 to 10 weeks with weekly teleconference meetings in between. An online data directory will be established for the sharing and approval of design documents.

The final edited script will be developed in an online data document for collaborative editing and review. Specialist consultants as well as the museum will be invited to comment and correct the content as it is developed. Translations will be added at this stage Commissioned illustrations will be finished and incorporated into the finished artwork.

Task 5: Installations

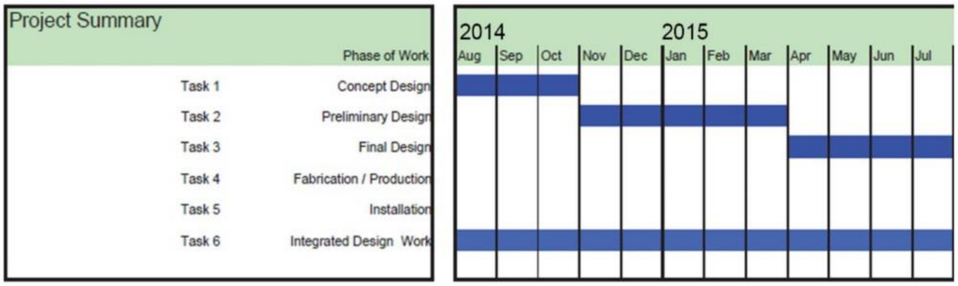
(6 months)

Our local partners, Purcell Miller Tritton Hong Kong and Buro Happold (HK) will be available to monitor on site installation on a weekly basis. We have also assumed a monthly meeting with all the design team and fabricator to ensure that details are dealt with in a timely manner. On review of the size of the galleries and our understanding of the type of work involved we have reduced the overall time allocated to the fabricator to build and install the exhibits by two months. This will allow a two-month test and training period before the November opening of the new Museum.

Task 6: Integrated Design

As referenced above the main tasks noted under the Integrated Design Task will be incorporated into the main work schedule. Research, scriptwriting and developing of unique and accessible exhibits is our goal for this museum and a key partner will be Dr. George Forster and his team of specialist subject consultants such as Professor Colin Pillinger, famous for his involvement in the British attempt to land an exploration Rover on Mars, but also widely consulted on all issues of current space exploration, even on Chinese projects. Graphic design will be led by the studio but with the option to use a Hong Kong based designer to complete artwork, especially Chinese language layout and editorial. All those design materials will be stored online for ease of access and will be downloaded to a store of the Museums choosing at completion of the project to serve as a comprehensive archive for the future.

Appendix 5.1 Project summary for HKsM



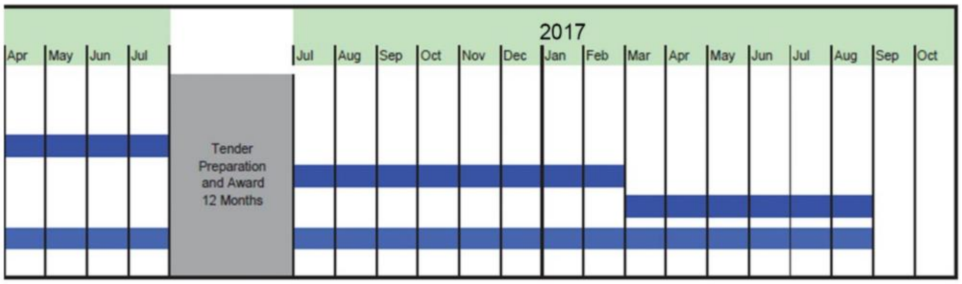
Staffing Summary / **Staffing - Resource days per month**

Name	Role	Mth 1	2	3	4	5	6	7	8	9	10	11	12
Exhibit Design													
Richard Houghton	Chief Designer	5	5	10	5	5	5	4	4	3	3	5	5
Kate Kneale	Project Manager	3	1	3	1	1	1	1	3	1	1	1	1
Robert Sawers	Chief Engineer	10	10	10	10	10	10	10	10	10	10	15	15
Jennifer Jiayi Jin	Senior Designer	6	6	6	6	6	6	6	6	6	6	6	6
Davide Nava	Designer						10	10	10	15	15	15	15
Graphic Design													
Kam Rehal	Senior Designer			5		5		5	5			4	6
Hyeyoung Jeong	Designer												
Consultants													
PMTHK	Design and management (HK)	1	1	1	1	1	1	1	1	4	4	4	4
Kempt	Games Consultant	4	4	4			5	1	1	6	6	1	1
Buro Happold	Lighting Design			2				4	4			10	10
BoostEd	Research & Script includes specialist consultants	4	4	4	4	4	4	4	4	4	4	4	4

Travel and Attendance / **Attendance on Site per month**

Role	Totals	Mth 1	2	3	4	5	6	7	8	9	10	11	12
Chief Designer	30	3		3			3		3	3			3
Chief Engineer	47	3		3	3		3		3	3		3	3
Project Manager	25	3		3					3				
Other Staff and Consultants	10								2				2
Chief Researcher & Script Writer	31	3		3			3		3	3		3	3
	Attendance	12	0	12	3	0	9	0	14	9	0	6	11

Note 1: The exhibition of HKsM is located in two galleries each with a distinctive look and feel. The Hall of the Cosmos, set around the planetarium dome, is a complex shape with ceiling heights varying from 20 to 30 metres (curving) down to 3.5 metres. The Hall of Space Exploration is on the first floor and separated from the first hall by a flight of stairs and the lobby.



9	10	11	12				25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
3	3	5	5				3	1	1	1	1	1	2	1	1	2	2	1	1	4		
1	1	1	1				3	1	1	1	1	1	1	1	1	2	3	1	1	8		
10	10	15	15		12		10	10	10	10	10	10	10	10	10	10	8	8	8	8		
6	6	6	6				6	6	6	6	6	6	6	6	6	6	8	8	8	8		
15	15	15	15																			
		4	6				6	6	6	6	6	4	4	4	4	4	2					
											10	10	10	10								
4	4	4	4				6	6	6	6	6	6	6	6	6	6	6	6	6	6		
6	6	1	1																			
		10	10																	5		
4	4	4	4				4	4	4	4	4	4	4	4	4	4	4	4	4	4		

9	10	11	12				25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
3			3				3						2			2	2			3		
3		3	3				3			2			2			2	2	2	2	8		
							3									2	3			8		
			2							2			2							2		
3		3	3				3									2	2	0		3		
9	0	6	11	0	0	0	12	0	0	4	0	0	6	0	0	8	9	2	2	24		

Note 2: HKD is a member of the Museum Association. Creative Director of the firm–Richard Houghton is a Fellow of the Chartered Society of Designers.

Note 3: HKD studio designed these two galleries together, Kate Kneale mainly in charge of the Hall of Space Exploration, and Jennifer Jiayi Jin (the author) in charge of the Hall of the Cosmos.

Note 4: The following document details the project management of HKD's policy.

Project Management

HKD's policy is to provide design services that meet the needs of our customers and exceed their expectations. This is done via a system of procedures that reflect the competence of the company to meet standards of quality, safety and environmental management, and to demonstrate this to existing customers, potential customers, and independent auditing authorities.

Achievement of this policy involves all staff, who are individually responsible for the quality of their work. This policy is provided and explained to each employee by the Creative Director, who retains overall responsibility for monitoring the services provided by HKD Ltd.

All HKD design services are assessed for risk at key stages through our quality control procedures and regular project review meetings. All risk (financial, physical etc) are continually monitored and reviewed to ensure compliance with relevant statutory and safety requirements.

In the implementation of services such as exhibit, display and structural design, prototyping is employed to ensure all elements adhere to safety requirements. HKD seeks to continually review and amend its procedures to meet the demands of our clients and our organisation.

The Quality Assurance system of the Design Studio is based on ISO 9001. This includes but is not limited to:

- a set of procedures that cover all key processes in the business
- monitoring processes to ensure they are effective
- keeping adequate records
- checking output for defects, with appropriate and corrective action where necessary
- regularly reviewing individual processes and the quality system itself for effectiveness
- facilitating continual improvement

Appendix 5.2 Extended exhibit matrix

In developing the exhibition story and content to prepare a response to the space we have added a number of additional exhibits and described their possible function so as to better tell the story of space exploration and the cosmos.

List of exhibits added to content in brief:

		Entrance	
0. Lobby and Exterior			
Exhibit Number	**Name**	**Description**	**Method**
0.1	Exterior screen wall over entrance	Mural graphic celebrating space exploration and the science of Astronomy. Incorporating coded light sequence that changes every day with new piece of information celebrating space science - inspired by the continually changing title search page on Google, but in binary.	Mural graphics and computer controlled LED light sequence. Clues to the meaning of the binary can be found on the Museum website
0.2	Entrance Lobby - rear wall	Glazed wall at back of lobby is transformed by transparency photo panels that are back-lit by the natural daylight of the window.	Graphic Mural panels
0.3	"Space book" or the Social Universe	Accessed via web and mobile app, this meta experience is essentially a social network that ties together online educational elements (e.g. promoting crowd-source projects such as Zooniverse and Stardust@Home), fun micro games and sustained engagement 'persistent' games.	Computer stations in the Lobby allow visitors to log on to and create avatars if they have not done so already at home. Descriptive information about the quests and rewards to be pursued through the museum will be managed from here.
I. The Sun (Life Giving Sun: Basic Solar Science)			
Exhibit Number	**Name**	**Description**	**Method**

1.2	Facts and Figures	Images and data about the Sun and its relationship to Earth	Graphic panels with simple interactives such as lift flaps and Lenticular prints embedded in display.
2. The Solar System **(Our Solar System: The latest discoveries about the Solar System)**			
Exhibit Number	**Name**	**Description**	**Method**
2.9	Solar System Model	Key exhibit illustrating the orbits of the planets and their elliptical paths.	A table projection surface with the orbits of the planets marked on. A large cone alongside has removable sections that can be placed on the table to match the elliptical orbits of the planets. Simple plastic shapes could also be used. RFID tags in the elliptical conic sections trigger additional projected animations.
3. The Earth (Our Home: The Earth)			
Exhibit Number	**Name**	**Description**	**Method**
3.1	Planet Earth	Changing shows projected onto sphere showing earth from space - at night, the weather patterns, ocean currents, etc.	Science on a Sphere presentation onto large sphere projection surface with four projectors to give 360 degree viewing. Show different aspects of Earth e.g. continental drift, atmosphere, effects of climate change.
3.5	Constellations	Overhead display with story about early fascination with 'the heavens' and key scientists	Projected onto curved wall a video presentation that runs at set times in this part of the gallery.
3.9	Goldilocks Zone	Life on Earth - why is our planet 'just right'?	Diagram of Solar System with slider below. Visitor moves slider to get comparative readout. Animated cartoon creature melts or freezes accordingly.

3.10	Visit the Moon	A detailed computer model of the moon viewed through a moon Lander cockpit simulation.	Simulation of cockpit with flight controls and view of moon through viewports. Visitor flies to destinations on the Moon.
3.13	Craters	Visitor 'bombards' powdered surface with balls to observe cratering to surface.	A large pool of powder under Perspex canopy. Explanation of crater diameter in relation to size of meteorite and momentum.
4. Star Lab (Star formation, stellar evolution)			
Exhibit Number	**Name**	**Description**	**Method**
4.4	Counting stars	How do we know how many stars there are? We can only estimate. Count a small sample and then make your own estimate.	A large cube of glass filled with marbles. A smaller cube above it can be filled with marbles from the larger cube. Count the marbles in the smaller cube and make an estimate. The correct answer will then be revealed.
4.5	Puzzle of the week	A changing challenge for the mathematically minded.	White Board that looks like the workings of the Lab. A new puzzle can be displayed. Answer available on the web site?
4.6	Electromagnetic spectrum	Electromagnetic spectrum explained.	Slide a touch screen monitor along a wavelength chart and 'see' different aspects of the EMS, e.g. best wave lengths for photosynthesis, hot metal emissions, and sensitivity of some pigments to UV light.
4.9	Zeeman Effect of magnetism	The Zeeman Effect exhibit demonstrates how a magnetic field changes the colour and polarization of light emitted by gas energized by an electrical discharge. Studying this effect allows astrophysicists to learn about the magnetic fields of celestial bodies.	Exploratorium exhibit. http://exs.exploratorium.edu/exhibits/zeeman-effect/

5. Rest Area			
Exhibit Number	**Name**	**Description**	**Method**
5.1	Reading couches	Sculpted bench seats and selection of books and magazines on astronomy to read.	Books and magazines on shelves. QR codes could give access to more information.
5.2	Ball pond	Large area of soft balls for children to play in - older children can estimate number of balls in pond for	Plastic balls in a 'pond'
5.3	Astro News	Current updates on news stories in astronomy	Monitor relay of Astro-news feed.
6. Galaxies			
Exhibit Number	**Name**	**Description**	**Method**
6.3	Shape of the Milky Way	The current research into the form and shape of the Milky way, explaining the parts that cannot be 'seen' and the arms of the spiral galaxy, including our location.	Several puzzle pieces on table in simplified curve shapes and with RFID tags. The visitor has to position the pieces correctly on the table diagram to complete the map of the galaxy. A video animation projection overlays the table diagram with hints and information.
6.4	Doppler Shift	Demonstration of Doppler effect	Simple audio exhibit of moving sound source on a track with speed controlled by visitor.
6.5	Other galaxies	The amazing variety of galaxies that have been 'seen' by the Hubble Space Telescope	Kinect controlled interface allows users to select and enlarge images of galaxies with arm movements. Information about the galaxy increases the larger an image is enlarged.

6.6	Mapping the Milky Way	Demonstration game of how we can estimate the size and shape of the Milky Way with Doppler shift, but also how this does not work in all cases	A large board with two or three spiral arms as dials allows the visitor to position LED cluster lamps (representing gas clouds) at different positions on the 'arms'; the further out along the arm the lamp is placed in relation to our viewpoint in the centre of the dial the colour is changed to a darker red. Two or more clusters in line will have the same colour (the same Doppler shift) and therefore be indistinguishable for our observer on earth.
7. The Big Bang			
Exhibit Number	**Name**	**Description**	**Method**
7.1	The Big Bang	The Big Bang is the scientific description of the origin of the cosmos. It describes the beginning of the universe as an explosion of space, which has expanded and cooled ever since.	Through the interactive wall, visitors rewind the expansion of space and go backward in time, explore the galaxies crowd got closer and closer together. And ultimately, all matter and energy is compressed together.
8. The Universe (An Era of Chaos: How the Universe Evolved)			
Exhibit Number	**Name**	**Description**	**Method**
8.1	Chaos and attrac tion	Cone or cylinder is filled with small balls that are in constant motion. The visitor can introduce a static charged rod or ball to observe the balls cluster to it, representing the formation of gas clouds in the early universe.	Light weight plastic or styrene balls that can be attracted to a statically charged rod are blown about 'chaotically' in a cylinder. The visitor can push a rod into the cylinder through a small diaphragm and observe what happens.

8.2	Breaking symmetry	The effect of symmetry breaking in the early Universe was a series of phase changes, much like when ice melts to water or water boils to stream. A phase change is the dramatic change in the internal order of a substance. When ice melts, the increased heat breaks the bonds in the lattice of water molecules, and the ice no longer holds its shape.	A sculptural display of water in three states (solid, liquid and gas) in a glass chamber. Models of the molecular structure in each case are displayed alongside for the visitor to handle along with Oxygen and Hydrogen.
8.3	Space Surfing	Explore Gravity and the masses of planets and gasses by surfing through the universe exploiting the forces that hold the universe together.	Full size surfboard with motion sensor linked to animated film of gravity grid. Player uses the forces of gravity shown on the grid to move through the virtual
8.5	Large Hadron Collider	The search for the primary forces of the universe that will have established the first particles are being carried out at the Large Hadron Collider	Model of LHC with descriptions of search for Higgs Boson and Dark Matter.
8.8	Multiverse debating chamber	Exciting paradigm shift or victim of Occam's Razor? An introduction to theories of the size and multitude of the universe presented in an engaging way that allows several visitors to engage in structured investigation and encourages them to choose a favoured idea.	Place your vote on which theory you support. Short introductory films explain current theories with visitor feedback polling projected onto screens. Group interactive debating space for the exploration and dialogue around cosmic theories.
8.9	Backgr ound radiatio n	Images of the universe from the latest map generated by background radiation imaging.	Large graphic image, backlit.
9. Space / Time			
Exhibit Number	**Name**	**Description**	**Method**
9.1	Great minds think alike - or do they?	Three great scientists discuss topics in astronomy. We could have a number of different scripts with different sets of three astronomers	Actors play the roles of the scientists. Three screens display one astronomer each. They turn and talk to each other comparing the significance of their discoveries.

9.2	The fourth dimen sion	A simple video using graphics and special effects to explain the links between space and time. Includes some amazing "Did you knows"	Touch screen video presentation
10. Astronomy			
Exhibit Number	**Name**	**Description**	**Method**
10.7	What Would You Ask an Alien?	Search for Extra-terrestrial Intelligence	Screen based interactive. After a short introduction on Search for Extra-terrestrial Intelligence visitor can choose questions to ask an alien, feedback is given and a second series of question presented. Different avenues explore different life forms e.g. carbon based and the conditions necessary for life. Younger children can be encouraged to draw aliens and pictures can be displayed. This could be tied back to some given environments.
10.10	Survey station	Computers located at this position are linked up for collaborative programmes. Visitors see the progress status of the chosen project.	Computer workstations

Appendix 5.3 Exhibition digital and augmented spatial experiences

Digital technologies and augmented spatial experience provide a valuable and engaging element of the exhibition visitor experience. At their best, digital displays and HCI-driven interactives form an integrated part of the exhibition narrative and reinforce the learning objectives of the exhibition. They also leverage the digital tools and behaviours that visitors bring with them. Few visitors walk into the museum without a smartphone or tablet, and many of them remain "connected" throughout their visit, providing greater opportunities for visitor engagement beyond the Museum walls. Digital experience design is similar to exhibition design in that content, visuals, and technology are creatively combined to provide an experience for visitors that achieves specific learning objectives. A key part of the design process is determining when and how digital experiences should be incorporated into an exhibition, and the best methods to implement them.

Digital visitor experience design for HKsM focuses on several goals:

- Achieve the learning objectives and experience goals of the exhibition.
- Provide engaging experiences that leverage visitor behaviours.
- Increase enjoyment of the exhibition experience for target audiences.
- Whenever possible, extend the visitor experience beyond the exhibition walls.

For purposes of exhibition development, the museum's digital experiences are divided into two categories: in-gallery and online, they overlap significantly and are designed to be integrated and seamless for the museum visitor.

In-gallery – digital experience elements may include but are not limited to the following. Each of these can range widely in scope and complexity:

- Information Kiosks
- Interactives (in-gallery, sometimes reflected online)
- Digital Displays (media walls, immersive, etc.)
- Social Engagement
- Labels, Signage, Promotion

Online - digital experiences includes the Museum's website, social media channels, and mobile app. Rather than present separate online exhibitions or multiple mobile apps, the museum has focused on an integrated approach. Stories from all exhibitions are serialized and continually shared online, via the mobile app, and on social media. This approach enables remixing and personalization of content across exhibition themes. It also ensures visitors can find and engage with content based on their own interests.

The success of digital experiences is not only based on their design and function alone, but their placement, context, and the environment in which visitors encounter them. Digital experiences should therefore be conceptualized early in the exhibit planning process as an integral part of the exhibition design. For the purposes of internal discussion and simplification of process, here are digital component categories defined in more detail:

Digital Components

Information Kiosks - A touchscreen with multiple choices (buttons) visitors can use to select and view prepared content (videos, text and images, etc.). This is not considered "interactive" because visitors cannot tailor the experience or alter the outcome in any way.

Interactives - Interactives are designed to achieve specific learning and experience goals, ideally one goal, two at most. Users are given an objectives or goal to accomplish and ideally are guided toward completion of the goal (learn by doing). Users are able to control or influence the outcome of the experience. Both positive and negative feedback can support the learning objective(s). The interaction may involve a touchscreen or other type of controller (e.g., joystick).

Connecting to Online and Mobile - In-gallery connections to the Museum's website and mobile experience can include prompts to relevant digital content and to download the mobile app.

Social Engagement - Connecting to social media conversations, sharing opportunities within and outside the exhibition space, crowdsourcing and other participatory activities, and scheduled programs such.

Labels, Signage - Includes labels placed throughout the exhibition to link visitors to the website, social media, or mobile content. Signage inside the Museum promoting the Museum's mobile experience, and all of the physical to digital connections required to make visitors aware of the digital engagement available to them.

Augmented Experience Implementation Process

1) **Exhibition Digital Experience Team** - The digital experience team works together on digital components of the exhibition from early conceptualization through implementation. The digital experience team includes exhibition team members (curator(s), educator, and exhibition designer) and a Digital Experience design lead.

Note: Digital experience lead should ideally be a member of the exhibition core team to ensure digital experiences are conceptualized in concert with exhibition content.

2) **Digital Experience Plan** - Each exhibition should have an overarching digital experience plan. This plan is a living document that outlines the digital experience goals, scope of each component, and general plan for implementation. In particular, the plan should include how the in gallery and online experiences will work seamlessly together. As the project progresses, details of the plan are refined. This document serves as a reference as well as a record of decisions made throughout the project. One of more of the elements listed in the plan may have an individual experience narrative.
3) **Experience Narrative(s) -** For each major digital experience (interactive, digital display, etc), an experience narrative is developed. The experience narrative envisions what a visitor will see, hear, feel, do, and learn as they engage with the digital component. This narrative consider the entire visitor journey, from walking into the museum/exhibition to going online. This is also a living document that changes as project progresses and experiences are tested and refined.

Note: Individual experience narratives may not be necessary for smaller exhibitions where the Digital Experience Plan is sufficient to cover everything. Many exhibition projects begin with an experience narrative for the entire exhibition, not just the digital elements. This is recommended as it defines the entire visitor journey and can surface important details to be considered as the onset.

Appendix 5.4 Checklist of issues in developing exhibition interactives

Overview Issues

MUSEUM VISITORS

- Who is the target visitor (s) for the interactive?
- Is it appropriate for the exhibition's intended visitors?
- What is the audience looking for (entertainment, education, information, emotion, imagination, etc.)?
- Is the interactive likely to appeal to your visitors?
- Will it engage and excite a wide range of visitors?
- Will the visitors be apt to tell others about it?
- Will the visitors want to come back to experience the interactive again?
- Does it have flexible outcomes for repeat visitors?

OBJECTIVES

- Are there clear objectives for the interactive?
- What is the intent or desired outcome of the interactive?
- What kinds of experiences does the interactive encourage? (e.g., learning, imagination, memory, etc.)
- If learning is one, what is the educational goal of the interactive?
- What kind of meaning will it have for users?
- Are the goals for the interactive part of an overall interpretive strategy in the exhibition?
- Do they directly relate to the concept and goals of the exhibition?
- Is it really answering a need or adding to an exhibition in a meaningful way?
- Is the point of the interactive reinforced in the exhibition?
- How does the interactive relate to the exhibition experience?

EFFICIENCY

- Can this interactive be used for other purposes?
- What is the intent or desired outcome of the interactive?
- What kinds of experiences does the interactive encourage? (e.g., learning, imagination, memory, etc.)
- Is the interactive one aspect of a multi-part project (exhibition, book, lecture series, films, etc.)?

BUDGET

- What is the estimated cost of the interactive exhibits?
- Is money included for several stages of prototyping with visitors?
- Is money included for repair/maintenance?
- Is the cost of measuring outcomes a part of the budget?
- Are all appropriate staff members involved in estimating cost? (Curators, exhibitions staff, tech staff, etc.)

Development of Content and Design

CONTENT

- Is this interactive technology-driven rather than content-driven or experience-driven?
- What are the main experiences/ideas the interactive is going to present/teach?
- Is this the content best suited to the device?
- Does the content fit into, enhance and support the central aims/themes of the exhibit? Is the content extraneous?
- What is the scope of the content (should be narrow, could be layered if necessary)?
- Is there a good match between the content and the technology?

  (The interactive shouldn't be exclusively informational or "educational" but should have a mix of intended outcomes.)

DESIGN OF AR INTERACTIVES

- Are augmented reality technologies been carefully selected?
- Are developer working on the target AR software platform?
- Will the program allow multiple paths to desired outcomes?
- Will the program allow multi-visitors to participate together?
- Are they able to keep the user's interest and engagement high, and provide ways to support different "layers of activity"
- Does the interactive have the capability of providing statistics on its use by visitors?

DESIGN AND THE AUDIENCE

- What are the museum designer's expectations for the experience of the interactive?
- What are the likely visitor expectations for the experience of the interactive?
- What are the cues that trigger those expectations in visitors?
- How does the interactive fit into the flow of the visit experience?
- Will multiple interactives build on or complement each other?
- How long will each visitor use the interactive?
- How easy is it for a visitor to figure out how to use the interactive?
- Is it immediately intuitive how to interact with it?
- How much of that instruction can be built into the design rather than text?
- Is it easy to operate and understand?
- If computer-based, is it easy to navigate?
- How many visitors can it accommodate?
- Does it encourage experiences with other visitors, either in the group or outside it?
- Can visitors get the outcome by observation or do they need to work the interactive themselves?
- How can users be creative with this program/interactive?
- Can the activity be accomplished quickly?

Appendix 5.5 Selected augmented spaces inside the Hall of the Cosmos

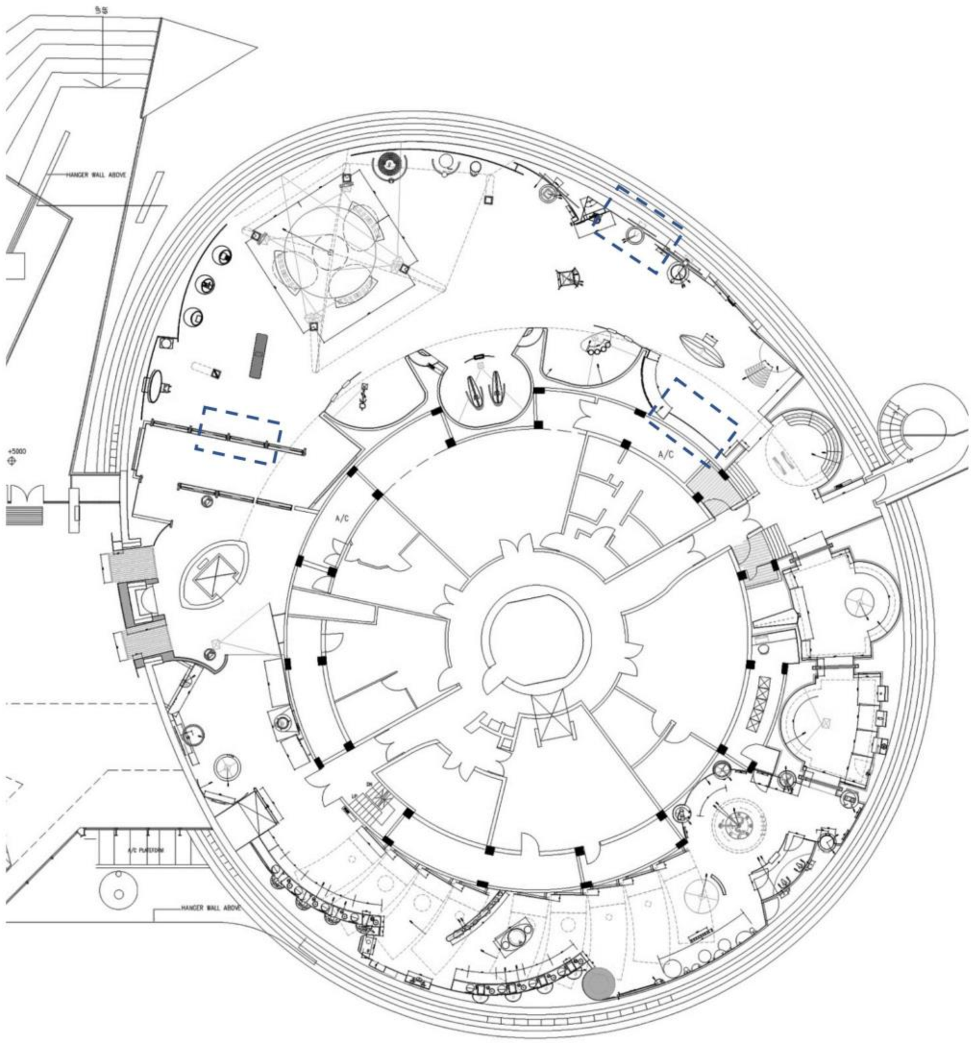
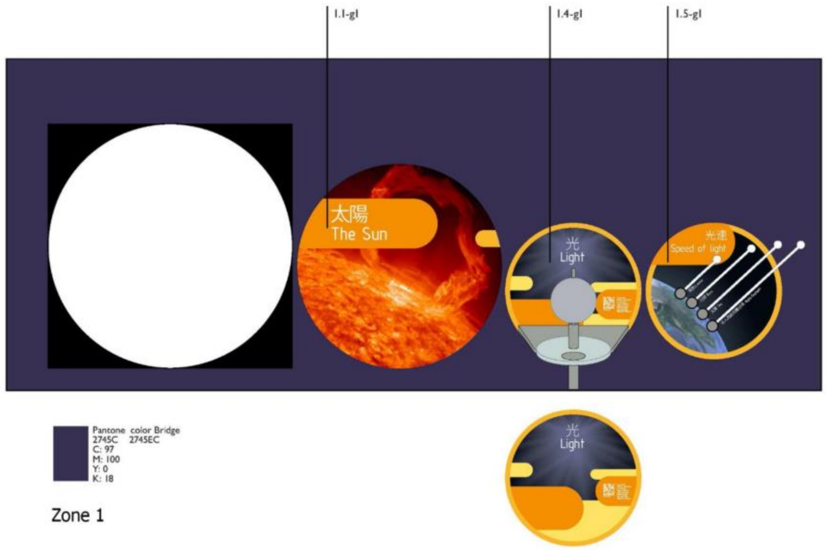


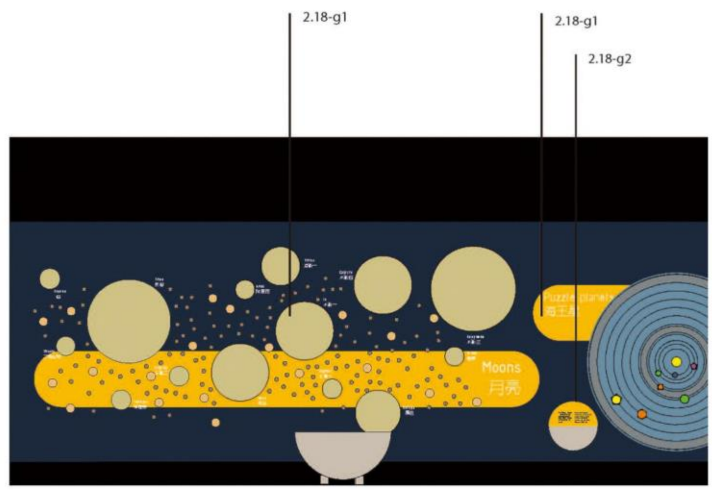
Figure: Zones 1-10 for the Hall of the Cosmos, Hong Kong Space Museum.

Source: HKD Studio



Pantone color Bridge
2745C 2745EC
C: 97
M: 100
Y: 0
K: 18

Zone 1



Pantone
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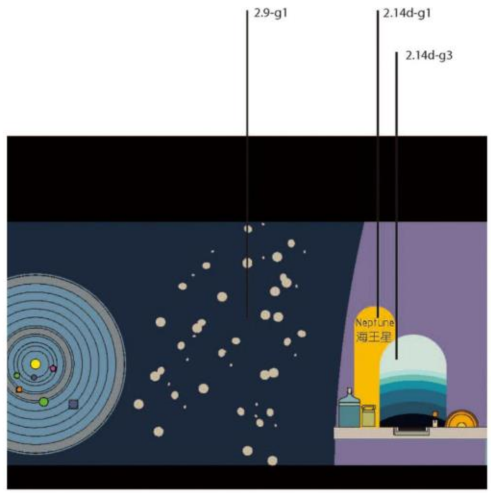
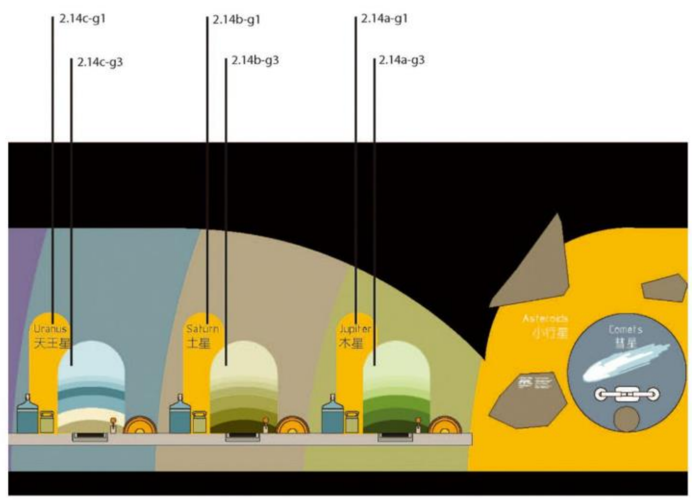
M: 71
Y: 9
K: 58

Zone 2

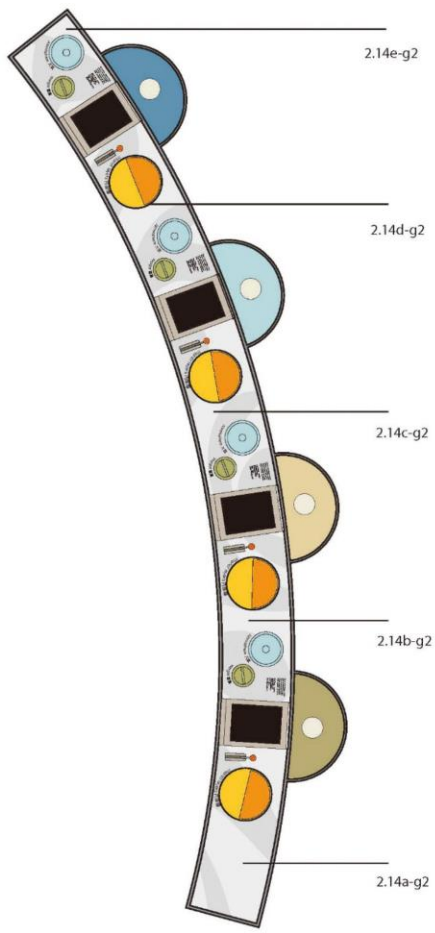

2.9-g1
2.14d-g1
2.14d-g3
Neptune
海王星

Zone 2

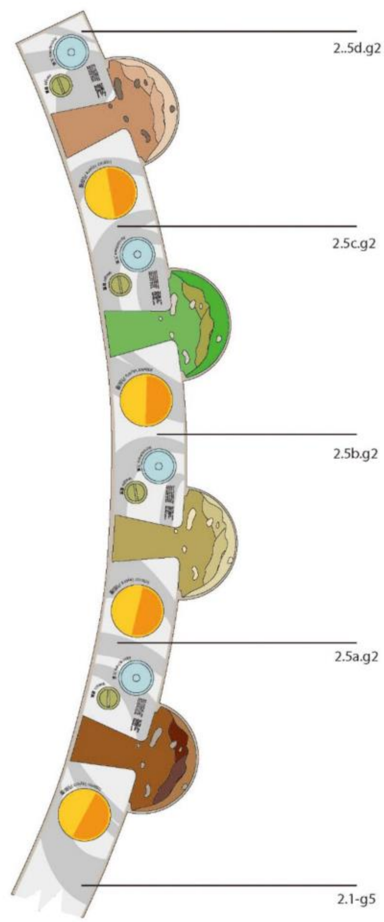

2.14c-g1
2.14c-g3
2.14b-g1
2.14b-g3
2.14a-g1
2.14a-g3
Uranus
天王星
Saturn
土星
Jupiter
木星
Asteroids
小行星
Comets
彗星

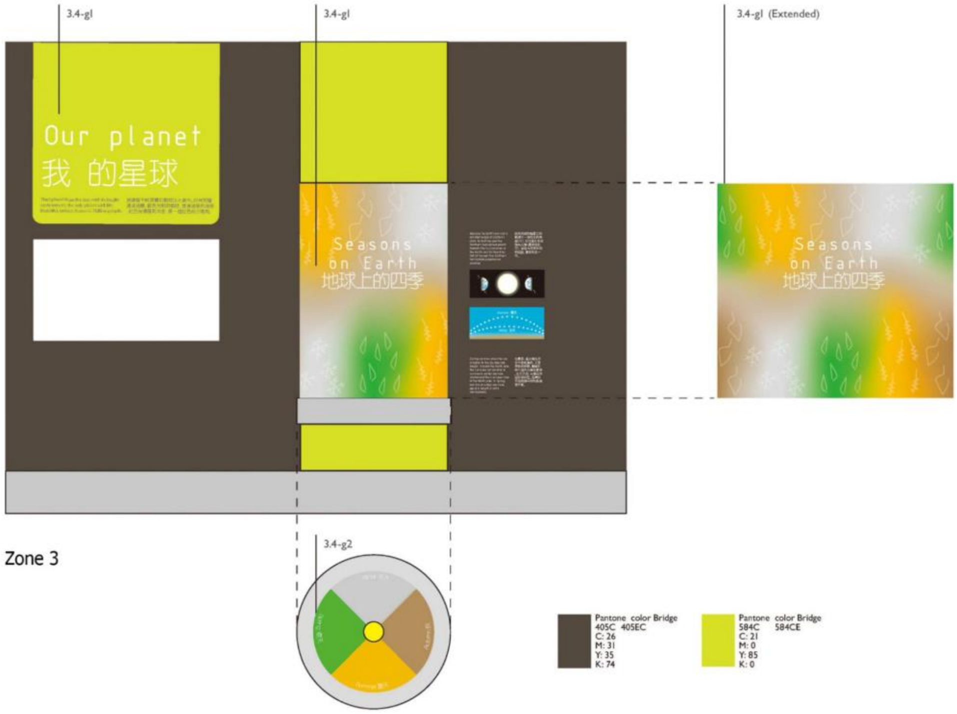
Zone 2

Zone 2


2.14e-g2
2.14d-g2
2.14c-g2
2.14b-g2
2.14a-g2

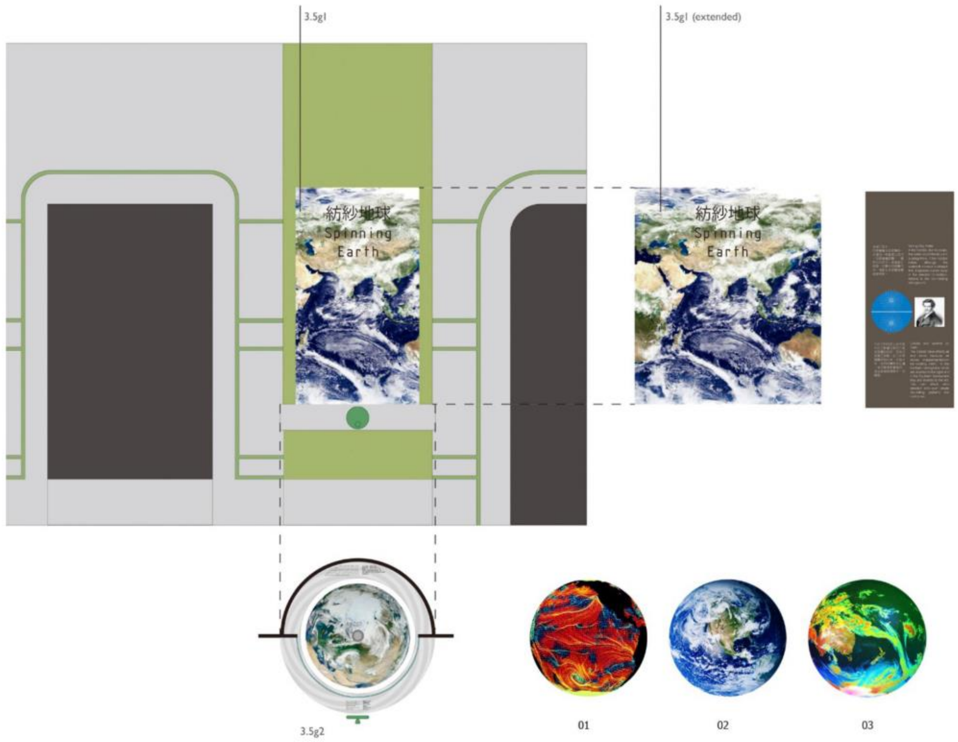
Zone 2


2..5d.g2
2.5c.g2
2.5b.g2
2.5a.g2
2.1-g5



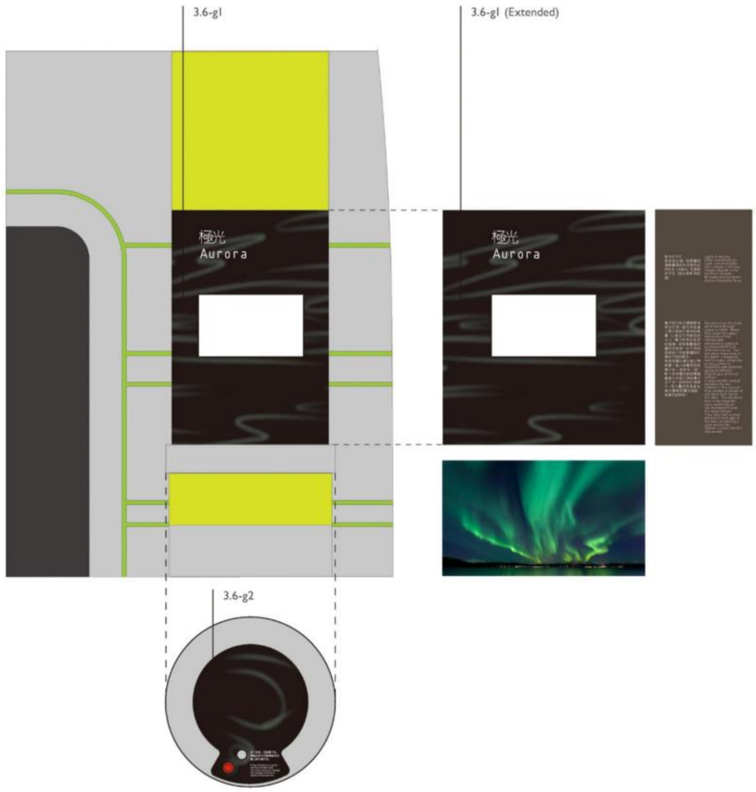
Zone 3

Augmented Space Design - Interactive projection floors

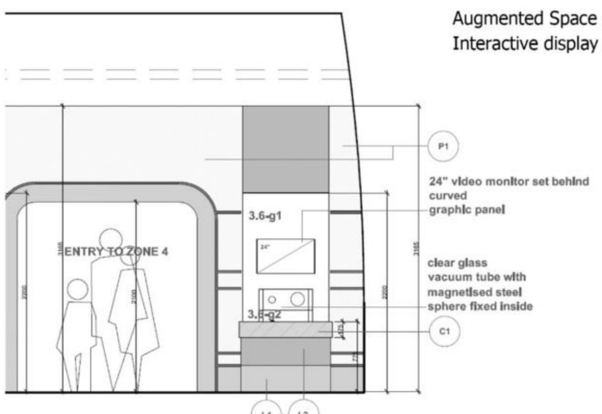


01 Wind patterns over the Pacific Ocean
02 The major surface wind bands of Earth
03 Global weather 3D

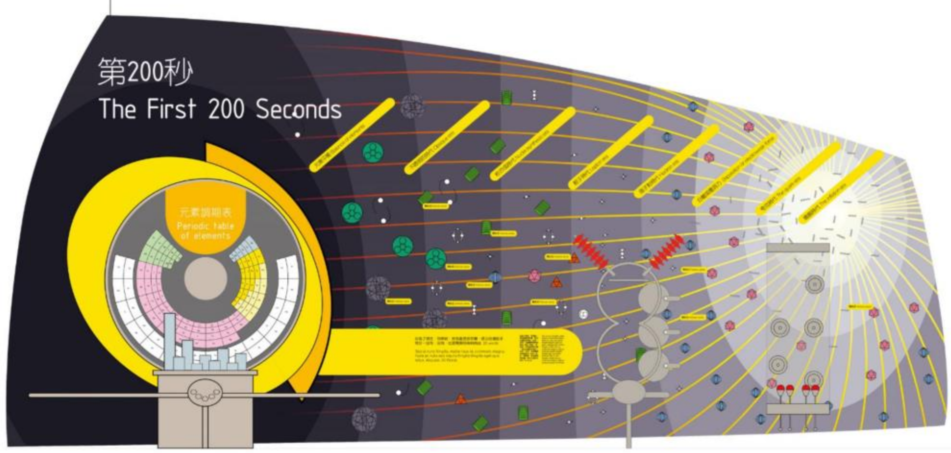
Augmented Space Design -
Floating Projector Sphere

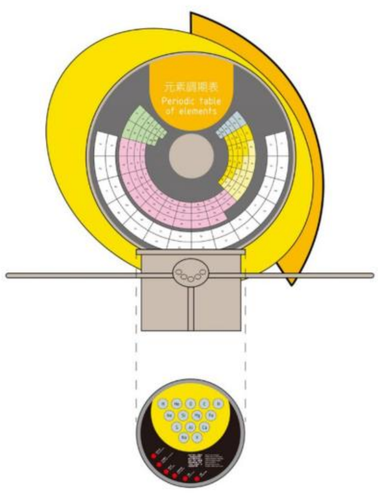


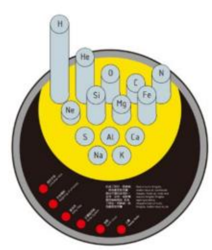
Augmented Space Design -
Interactive display



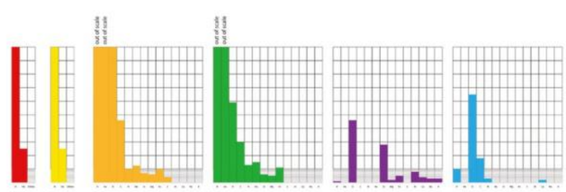
6.1-g1

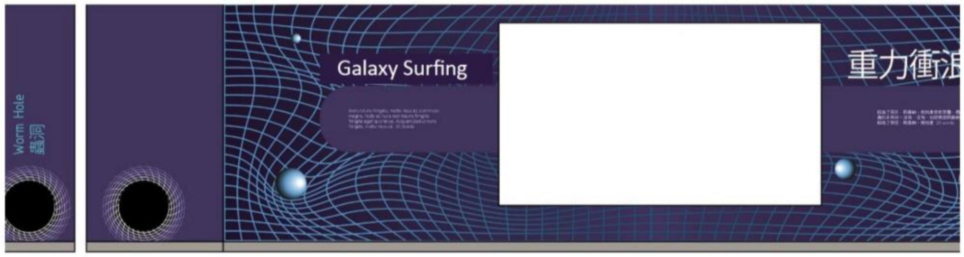






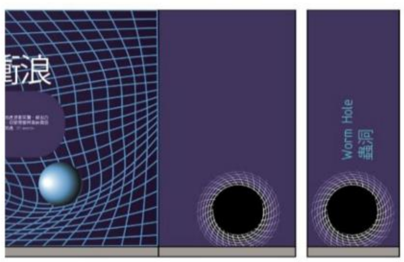
Augmented Space Design
The First 200 Seconds +
Chronology of the Universe



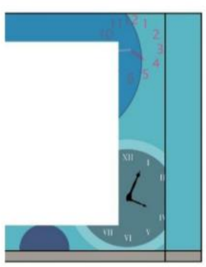


Pantone color Bridge
484C 484EC
C: 8
M: 94
Y: 99
K: 34

Pantone color Bridge
319C 319EC
C: 62
M: 0
Y: 20
K: 0



Augmented Space Design
Gravity Surfing and
Relativity Bicycle



Appendix 5.6 Featured augmented space design – the Galaxy Surfing Experience

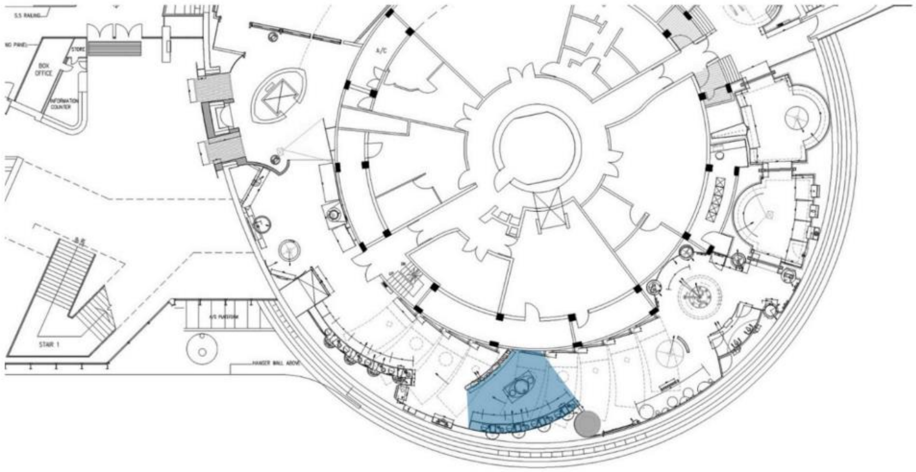


Figure: The location of the featured augmented space for the Galaxy Surfing Experience, coloured in blue.

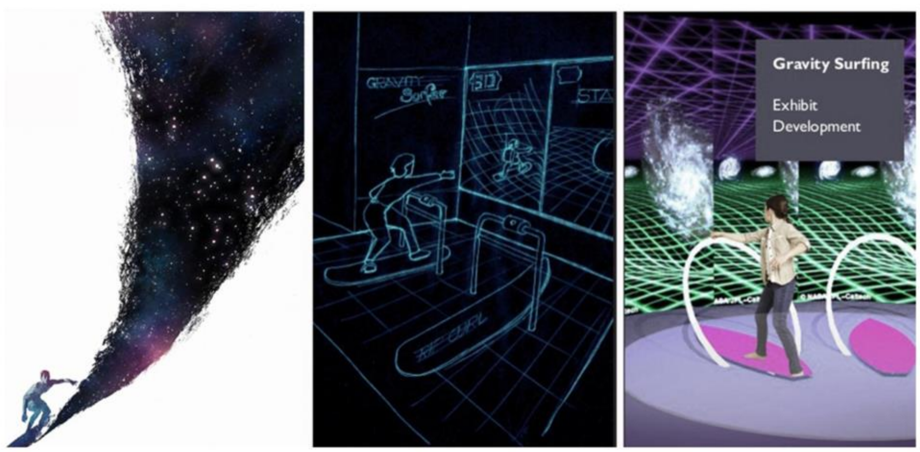
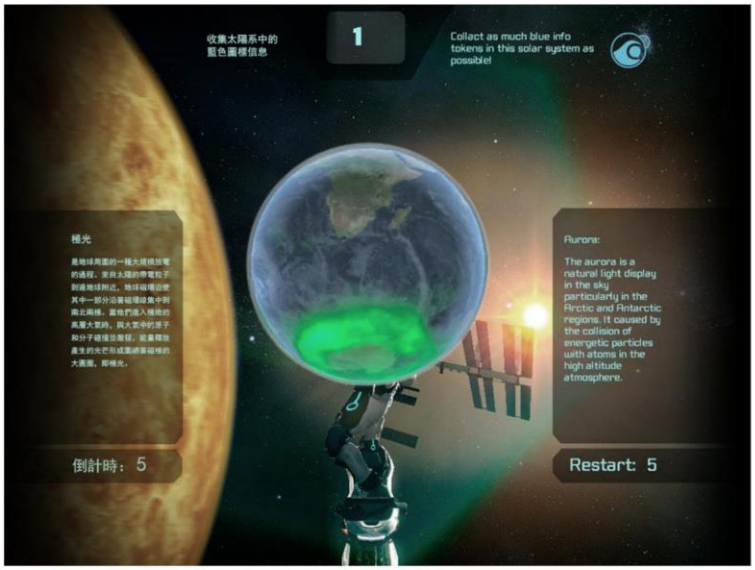
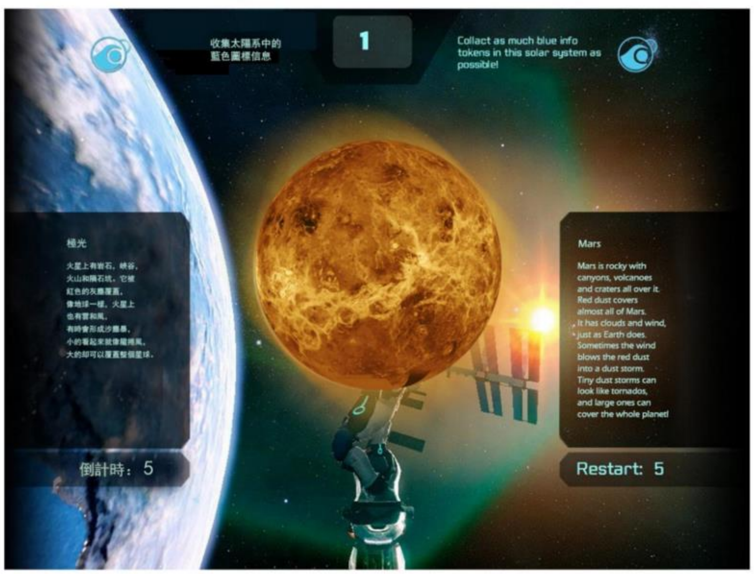


Figure: Left: The concept image of the Galaxy Surfing Experience; Middle: The hand-drawing of the Galaxy Surfing Experience; Right: The primary design of the augmented space.



Interface Design (1)
for Galaxy Surfing



Interface Design (2)
for Galaxy Surfing

Figure: The interface design for the Galaxy Surfing experience

Source: HKD Studio

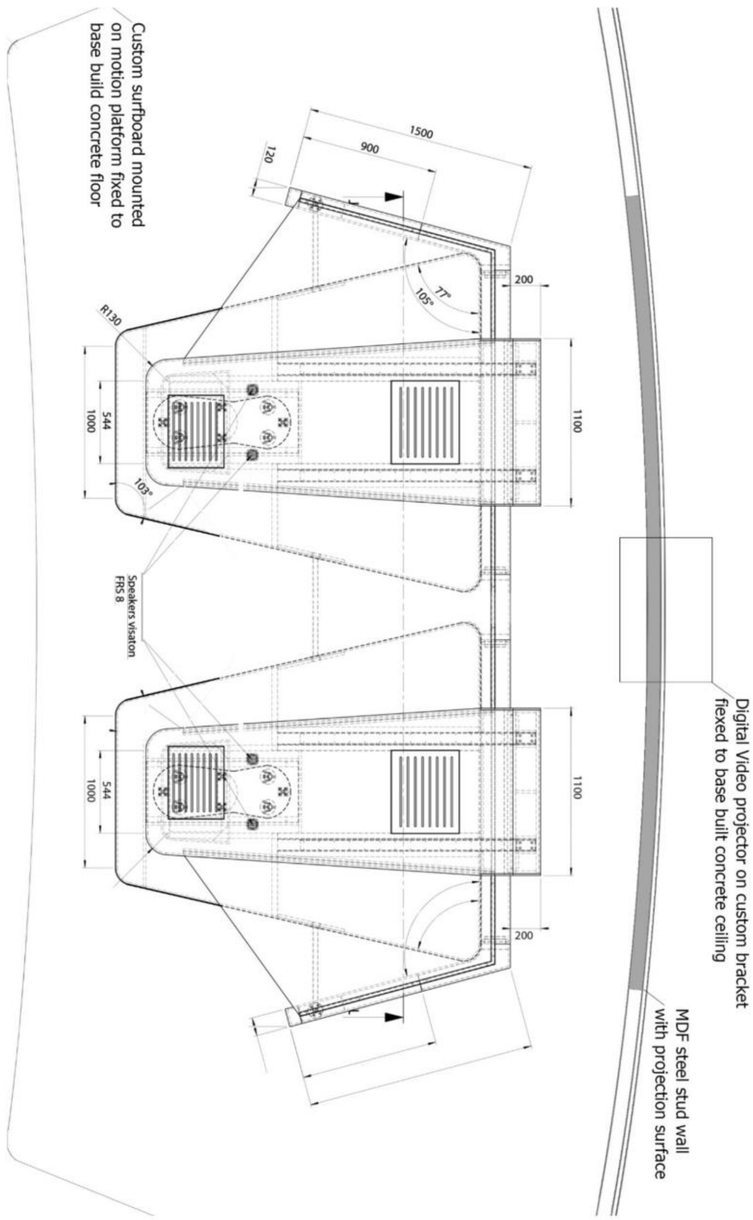


Figure: The plan of the augmented space design for the Galaxy Surfing experience

Source: HKD Studio

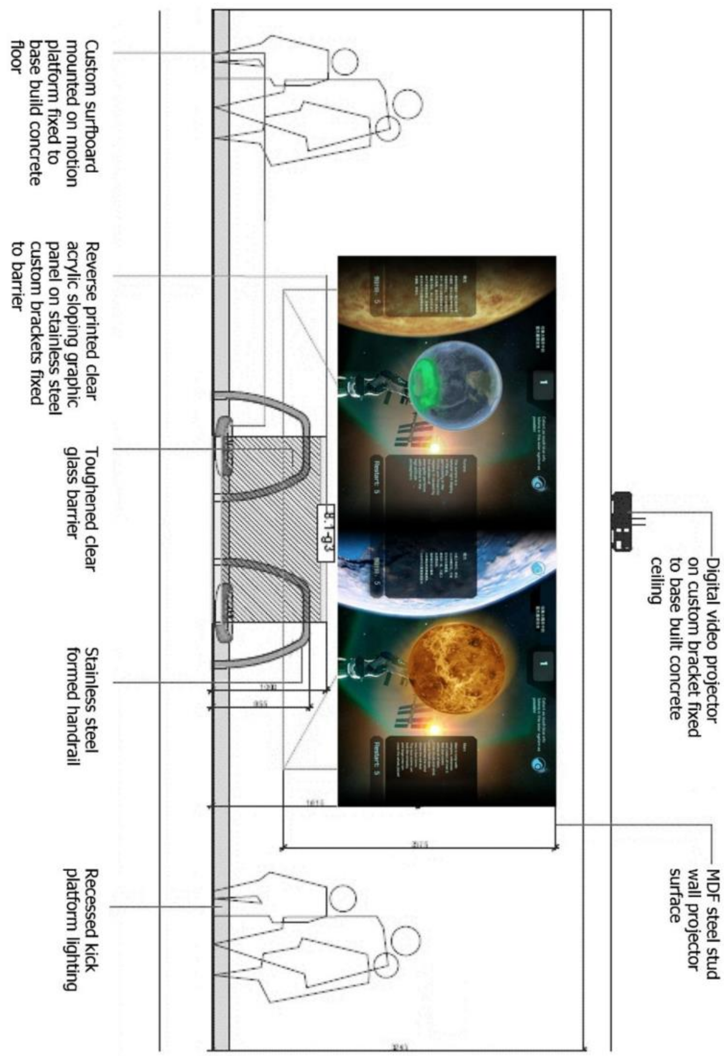
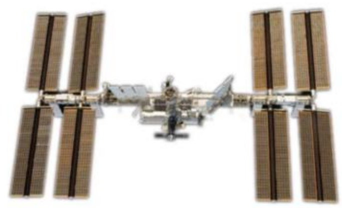
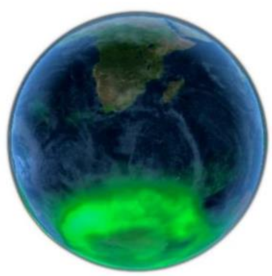
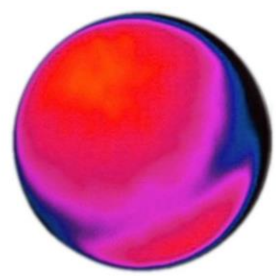


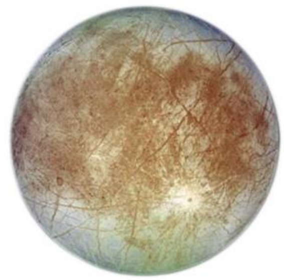
Figure: The elevation of the augmented space design for the Galaxy Surfing experience

Source: HKD Studio

Game Checkpoint

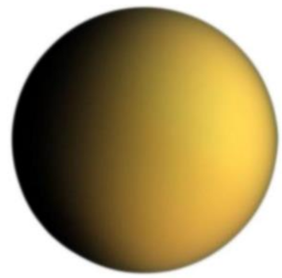
	
Checkpoint 1: The ISS is the largest space vehicle ever built. It flies at an altitude of about 200 miles, with an average speed of approximately 18.000 miles per hour.	Checkpoint 2: Sometimes called the dark side of the Moon is the lunar hemisphere that is never visible from the Earth. The moon does not revolve around its axis!
	
Checkpoint 3: The aurora is a natural light display in the sky particularly in the Arctic and Antarctic regions. It caused by the collision of energetic particles with atoms in the high-altitude atmosphere.	Checkpoint 4: Mercury's temperature fluctuates enormously between day and night. During the day temperatures hit 430 degrees centigrade whilst at night it is -180 degrees. This is because 1 day on mercury lasts for 176 earth days.

	
Checkpoint 5: Venus is the second planet from the Sun, orbiting it every 224.7 Earth days. It is the second-brightest natural object in the night sky after the Moon. Venus has an extremely dense atmosphere. The pressure at the planet's surface is 92 times that of Earth's surface: a pressure equal to a depth of nearly 1 kilometre in earth's oceans.	Checkpoint 6: Phobos is the first moon of Mars. Phobos orbits 6,000 km (3,700 mi) from the Martian surface, closer to its primary body than any other known planetary moon. Its orbit is perfectly circular and maybe, far in the future, Phobos might crash into Mars.
	
Checkpoint 7: At this moment, there are two rovers driving around Mars. They are taking pictures of the soil and rocks. In this way, we will discover more about Mars, and maybe, next to ice, there is water to be found.	Checkpoint 8: Deimos is the outer moon of Mars and with a length of 10 miles also the smaller of the two. This makes it one of the smallest known moons in the solar system.



Checkpoint 9: Jupiter is the biggest planet in the solar system. It is a giant planet with a mass one-thousandth that of the Sun, but two and a half times that of all the other planets in the Solar System combined. It is a stormy gas giant. The red eye of Jupiter is a storm that has been raging on for over 300 years.	Checkpoint 10: Europa is the sixth moon of Jupiter and slightly smaller than Earth's Moon, Europa is primarily made of silicate rock and has a water-ice crust and probably an iron–nickel core. In 2012 ESA will launch a mission to this ice moon for further exploration.

Checkpoint 11: Io is the moon of Jupiter that is closest to this huge planet. With over 400 active volcanoes, Io is the most geologically active object in the Solar System.	Checkpoint 12: Ganymede: This moon of Jupiter is enormous! It is as large as planet Mercury and this makes it the largest moon in our solar system.

	
Checkpoint 13: Just as our own moon, Callisto always faces Jupiter with the same side. Callisto has about 99% the diameter of the planet Mercury but only about a third of its mass. Callisto is composed of approximately equal amounts of rock and ices.	Checkpoint 14: Titan is the largest moon of Saturn and has, as the only moon in the solar system, a dense atmosphere.
	
Checkpoint 15: Saturn is the least dense planet in the Solar System. It is made up of mostly hydrogen and helium, which are the two lightest elements in the Universe. At higher pressures, below the determined surface, hydrogen on Saturn becomes liquid.	Checkpoint 16: Planet Saturn has 7 rings around it, consisting mainly from ice. The rings are amazingly thin, estimated to be less than a kilometre thick. The rings are made up of ice and rock pieces that create a rainbow effect as they refract the light from the sun.

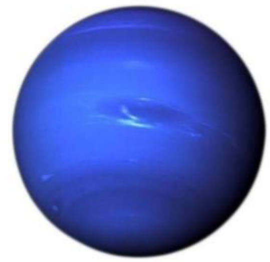
	
Checkpoint 17: The first 8 planets orbit the Sun while keeping the same distance from the Sun. Pluto orbits in an ellipse and sometimes crosses paths with Neptune. This is one of the reasons Pluto is not called a planet.	Checkpoint 19: Neptune is the 8th and last planet in the solar system. Because Neptune is so far away from the sun, one year on this planet lasts 165 earth years!
	
Checkpoint 18: Uranus is a frozen gas planet and has, just like Saturn, rings made up of ice. Uranus does not spin as the other planets, but is tilted on its side. It is the coldest planetary atmosphere in the Solar System, with a minimum temperature of 49 K (−224 °C; −371 °F), and has a complex, layered cloud structure with water thought to make up the lowest clouds and methane the uppermost layer of clouds.	Checkpoint 20: Voyager is the furthest object in space ever made by man. They were launched in 1977 to take advantage of a favourable alignment of Jupiter, Saturn, Uranus, and Neptune, and are now exploring the outer boundary of the heliosphere in interstellar space. This discovery vehicle almost exits our solar system. Voyager's signal takes almost 11 hours to reach planet Earth.

Table: All the scientific knowledge behinds checkpoints for the Galaxy Surfing experience

Source: HKD Studio