Interactive Storytelling in Mixed Reality

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A catalogue record is available from the Eindhoven University of Technology
ISBN 978-90-386-3771-6

Proefschrift Technische Universiteit Eindhoven
Keywords: Interactive Storytelling / Mixed Reality / Entertainment computing / Context-aware system / Cultural computing / ALICE project / Design tools / User experience

Typeset with LaTeX
Cover design by Preplet - creative studio, Skopje, Macedonia
Printed by Ipskamp Drukkers, Enschede, The Netherlands

Interactive Storytelling in Mixed Reality

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
rector magnificus prof.dr.ir. C.J. van Duijn, voor een
commissie aangewezen door het College voor
Promoties, in het openbaar te verdedigen
op maandag 14 januari 2015 om 16:00 uur

door

Marija Nakevska

geboren te Shtip, Macedonië

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Interactive Storytelling in Mixed Reality

Summary

Immersive and interactive Storytelling is a form of digital entertainment in which an actual narrative is recreated into highly immersive and interactive fictional worlds where a user can have the experience of being a character in a story that unfolds based on her actions. We take advantage of novel technologies, by merging real and virtual worlds to produce new environments that confront the user in an intense and a seemingly real experience. The user is physically immersed in the narrative, co-creates the story, and interacts with the space instead of watching on a screen.

This research is part of the project ALICE which creates an experience based on selected parts from the novel "Alice's Adventures in Wonderland" by L. Carroll. The ALICE installation covers two floors each with an area size of 12 by 12 meters, and it comprises six separate stages, each of them using a large palette of technologies, such as sensors, actuators, virtual reality, and embodied and virtual agents. Each stage of the installation utilizes a dedicated space that simulates a certain environment, e.g., nature mimicking, simulation of falling, or changes of the perception of the relative size of the space, which correspond to different parts of the narrative.

This thesis explores the design challenges that concern the building of this type of immersive and interactive environments. The research was done in a close cooperation with designers, architectural, electrical and mechanical engineers. Design knowledge was acquired from the fields of computer science, interaction design, and psychology to identify the design challenges and the software and hardware requirements. The overall goal is to equip the design and the development teams with empirical knowledge, software tools and unified development environment that supports the process of creating interactive immersive environments.

The thesis is organized in three parts. In part one, we give overview on the developments of interactive storytelling in mixed reality environments. A theoretical overview of the established narrative theories is provided, that help us to define a theoretical model of the core story elements and the spatial and temporal relations. A technical state of the art overview presents the palette of technologies that allow merging of real and virtual worlds.

In the second part, we present the practical explorations in the ALICE project, we reflect on the design and development process and we propose a design tool to support the design process. Three stages from the ALICE installation are redesigned; reflection on the research objectives related to the system (technological objectives) and to the user experience (socio-cultural objectives) is presented. The design process in the ALICE project gave input for creating a design tool that supports the design and development process of such installations. The tool named *"Tell me a Story!"* is presented and the usage of the tool and the altered design process is demonstrated through a case study.

In the third part, we give a theoretical ground for understanding the user experience in interactive stories in mixed reality environments. Empirical evidence about the user experience in the ALICE installation is presented in two studies. The first study investigates the effects of sound

design and user's preknowledge of the story, and the second study looks into the effect of interactivity on the user experience and the behavior of the participants. Finally, we notice that the experience provided in the ALICE installation was very much appreciated and positively evaluated by over than 100 participants. We see great potential in this type of interactive entertainment.

Contents

1 Introduction 3

1.1 Research Objectives 4

1.1.1 Design challenges 4

1.1.2 Design process 5

1.1.3 User Experience 5

1.2 Methodology 6

1.3 Thesis Outline 7

I Background 9

2 Interactive Storytelling and Mixed Reality 11

2.1 Introduction 11

2.2 Interactive Storytelling 12

2.2.1 Traditional Storytelling 12

2.2.2 Games and Theme Parks 12

2.2.3 Digital storytelling 14

2.3 Mixed Reality 14

2.4 The Mixed Fantasy Framework 15

2.5 Related work: Mixed reality installations 17

2.5.1 Games, Museums and Exhibitions 17

2.5.2 Interactive Storytelling 18

2.6 The ALICE project 18

2.6.1 Cultural Computing and Interactive Storytelling in Mixed Reality . 19

2.6.2 Timeline and design team 20

2.6.3 The First ALICE Installation 22

2.6.4 Narrative 22

2.6.5 Stages 23

2.6.6 Empirical Studies, Reflections and Motivations for Redesign 26

3 Narrative Theories and Elements 29
3.1 Narrative Theories 29
3.2 Narrative elements 32
3.3 Characters 33
3.4 Spatial Setting 34
3.4.1 Design Elements and Principles 35
3.4.2 Spatial Design and Interactivity 37
3.5 Actions and Events 37
3.6 Time 38
3.7 Narrative Structure and Approaches in Interactive Storytelling 39

4 Technologies and Modalities for Mixed Reality Installations 43
4.1 Sensing 43
4.1.1 Context-aware Environments: Story as Context 44
4.1.2 Sensor Types 45
4.1.3 Approaches in Context-aware Systems 46
4.1.4 Communication Architecture 48
4.2 Physical Actuation, Robotic Characters and Special Effects 49
4.2.1 Rides 49
4.2.2 Robotic Characters 49
4.2.3 Special Effects 50
4.2.4 Safety 51
4.3 Video, Virtual Reality and Mixed Reality 51
4.4 Lighting Design 52
4.5 Sound 52
4.5.1 Sound Types 53
4.5.2 Sound for Interaction 54

II Design 57

5 Redesign of the ALICE Installation 59
5.1 The Second ALICE Installation 59
5.2 Redesign of Stage 1: "In the park" 61
5.2.1 Character: White Rabbit 62
5.2.2 Spatial immersion and storyplot 64
5.3 Redesign of Stage 2: "Down the rabbit hole" 65
5.4 Redesign of Stage 3: "Eat me, Drink me" 67
5.4.1 Spatial design 67
5.4.2 Interactivity 68
5.5 Control Structure 71

5.6 Conclusions 74

6 Tool for Design and Development of Interactive Stories in Mixed Reality **77**
6.1 Reflection on the Design and Development Process in the ALICE project . . 77
6.2 Roles in the Design Team 79
6.3 Requirements 81
6.4 Model Driven Engineering 82
6.5 Related Work 83
6.6 *Tell me a story!* a Tool for Authoring Interactive Stories in Mixed Reality . . . 84
6.6.1 Levels of Abstraction 84
6.6.2 Who: Agents 86
6.6.3 What: Events 86
6.6.4 Where: Place 86
6.6.5 With: Sentence 86
6.6.6 When & If: Drama Manager 87
6.6.7 How: Components and Modalities 89
6.6.8 Views and Interactive Story Engine 89
6.7 Execution Environment 90

7 A Case Study: Eat me, Drink me **93**
7.1 Design Iterations 93
7.2 Conceptualizing phase 95
7.3 Pre-production phase 98
7.3.1 Design process guided by the *Tell me a Story!* tool 98
7.3.2 Architectural and Spatial Design 100
7.4 Production phase 100
7.5 Evaluation phase 103
7.6 Conclusions and Future Work 103

III Experience **107**

8 Understanding the User Experience **109**
8.1 Introduction 109
8.2 The Embodied Narrative Engagement Framework 110
8.3 Presence 111
8.4 Dramatic and Narrative Presence 112
8.5 Agency 115
8.6 The Motivational Appeal of Interactive Storytelling Experience 115
8.7 Conclusions 116

9 On Sound Design and Users' Preknowledge of the Background Story 119
9.1 Introduction 119
9.2 Overview and hypothesis 120
9.3 Experiment 121
9.3.1 Method 121
9.3.2 Procedure and Participants 122
9.3.3 Measurements 123
9.4 Results 124
9.5 Interviewing Data and Discussion 126
9.6 Discussion and conclusions 129

10 The Effects of Interactivity on User Experiences 131
10.1 Introduction 131
10.2 Experiment 132
10.2.1 Procedure and participants 132
10.2.2 Measurements 133
10.3 Results 133
10.4 Discussion and Conclusions 135

11 Conclusions and future work 137
11.1 Contributions 137
11.2 Limitations and Future Work 140

IV Appendix 143

A Design tool 145

B Experiment forms 149

References 169

Listing of figures

1.2.1 The research project used in the thesis 6

2.3.1 Milgram's Reality-Virtuality Continuum 14
2.3.2 Mixed-fantasy framework (Stapleton et al., 2002b) 16
2.6.1 A timeline of the ALICE project (ALICE I), important events (left) and involved researchers, experts, technicians and designers (right). 20
2.6.2 The Alice installation 21
2.6.3 A participant in Stage 1: "In the park" 24
2.6.4 A participant in Stage 2: "Down the rabbit hole" 24
2.6.5 Stage 3: "Eat me, Drink me" 25
2.6.6 Stage 4: "The Pool of Tears" and Stage 5: "Advice from a Caterpillar" 26
2.6.7 Stage 6: transformations of the Cheshire Cat and a participant talking with the Chesire Cat 27

3.1.2 Chatman's diagram of the narrative elements (Chatman, 1980) 30
3.1.1 Freytag's five act structure (Freytag, 1872) 30
3.1.3 The forces of material and formal causality (Laurel, 1986) 31
3.1.4 The Neo-Aristotelian theory of drama (Mateas, 2001) 32

4.1.1 Basic components of a context-aware system interacting with a user (Meyer and Rakotonirainy, 2003) 48

5.0.1 Schematic drawing of the lower floor of the installation 60
5.1.1 Part of the ALICE II installation and part of the design team building prototypes and working in the control room 60
5.1.2 A timeline of this PhD project in relation to ALICE project, important events (left) and involved researchers, experts, technicians and designers (right). . . 61
5.2.1 Redesigned Stage 1 63
5.2.2 The redesigned White Rabbit: (a) user "following" the rabbit (b) "moving grass" prototypes; (c) the projected VR rabbit 64

5.3.1 *Stage-2 "Down the rabbit hole"* (a) *Stage -2*, the "rabbit hole" with bookshelves and lighting (b) The electronic seat and the security gate in the background. . 66
5.4.1 Schematic overview of the physical setting of *"Eat me, drink me"* stage. 67
5.4.2 Physical objects in the immersive environment 69
5.4.3 The virtual room and characters. (a) User inside the CAVE (b) VR door with interactive doorknob (c) White Rabbit in the Garden 70
5.5.1 Iteration 1: An implementation of a blackboard communication interface and a state machine for *Stage 3* 72
5.5.2 Iteration 2: Implementation of *Stage 1* to *Stage 3* 73
5.6.1 Implementation of the story characters and settings in the two different installations 76

6.2.1 Roles and activities of the contributing parties in the creation of an interactive storyworld 80
6.4.1 Overview of the design domain 82
6.6.1 Levels of abstraction in the design of Interactive Stories in Mixed Reality and views that are provided 85
6.6.2 Sentence defined in the tool *Tell me a Story!* 87
6.6.3 Nested story blocks 88
6.6.4 Interactive Story Engine 89

7.1.1 Iterative design process 94
7.1.2 A design process of developing interactive story scenario, with using the *Tell me a Story!* design tool 96
7.2.1 Part from the storyboard generated in the conceptualization (brainstorming) phase 97
7.3.1 The user interface for the Interactive Story Engine 101
7.4.1 The 3D models for the talking doorknob, the White Rabbit and garden . . . 101
7.4.2 Example of generated code 102
7.4.3 Schematic overview of the software (OSC:Open Sound Control). 103

8.2.1 Dow's Embodied Narrative Engagement (ENE) Framework (Dow, 2008): the combination of three experiential pleasures: presence, agency, and dramatic involvement. The material properties (perceptually immersive interfaces, interactivity, and narrative structures) are features of the medium that can be manipulated by creators. 110

9.3.1 Stage-3: (a) VR small white door, (b) opening of the door and view on the garden, (c) on of the VR doors projected on one of the other four sides, (d) bottle "Drink me", cookie box "Eat me" 122
9.4.1 Presence indicators in the AMSS and SS sound conditions 124

9.4.2 Presence indicators in the HPKS and LPKS variables 125

10.3.1 Dimensions of the presence(spatial presence, engagement, narutalness, negative effects), agency and satisfaction by treatment conditions: IE, NIE and NIMS 134

A.0.1 Drama manager 146
A.0.2 Generated Storyboard from the *Tell me a Story!* tool 147
A.0.3 Definition of the hardware and software components per agent and modality 147
A.0.4 Modalities and observers that handle each event 148

1 Introduction

Interactive storytelling is one of the more recent developments in interactive entertainment, which allows people to feel transported into a fictitious world as a story character, and to influence the unfolding events of a story. *Mixed reality*, by merging the real and the virtual, is a promising medium for creating interactive storytelling experiences that put the participants right "inside" a created storyworld. One of the most dramatic visions of this type of experiences was given by the classic *Star trek* TV series, with a device called the *holodeck*: The holodeck is a compelling vision for the creation of complete fantasy worlds with props, sets, lifelike characters, and scenarios capable of eliciting intense emotions. Referring to the metaphor of the holodeck, recently, many research projects have used the current state of the art of virtual and mixed reality settings to create highly immersive interactive storytelling systems.

Immersive mixed reality environments are *multisensory*, meaning they can stimulate the senses in a number of ways. Traditional screen-based entertainment is limited to audio-visual simulations, but immersive environments can also employ touch and smell, various forms of tactile sensations, physical movements and special effects like fog or snow.

Mixed reality environments have a high potential for creative endeavours in interactive storytelling. We are primarily interested in the integration of narrative and adaptive capabilities to the environments in which the user is immersed. We are also interested in a *context aware interaction* that is more involving and engaging than a conventional user interface. The experience we want the environment to provide is for *one person at a time*. The interactive environment reacts to the participant's inputs and behaviors, and constructs in real-time a personalized narrative and flow of events. This should yield an experience that reflects and influences the participant's mood and her state of mind. We assume that the immersion capacities of a mixed reality environment contribute essentially to, and enhance the *user experience* in the interactive story.

For this research, we used the ALICE installation, which creates an experience based on the selected parts from the novel "Alice's Adventures in Wonderland" by Carroll (1865). The ALICE installation comprises six separate stages, each of them using a large palette of hardware and techniques, such as sensors, actuators, embodied and virtual agents. Each stage of the installation utilizes a dedicated space that simulates a certain environment, e.g., nature mimicking or simulation of falling; which corresponds to a different part of the narrative (Rauterberg, 2006c, Bartneck et al., 2008, Hu et al., 2008).

In the pursuit to create a fully working prototype of an interactive mixed reality storyworld that spans through several physical spaces, we encountered most of the challenges that come along in the authoring, design and implementation of such a storyworld. However, there are still no established design frameworks and empirical knowledge that would guide the design process for creation of compelling story-based interactive mixed reality installations. The questions are: How do we transform the new technological capabilities of mixed reality environments, into future creative possibilities? And, how can the creators of these immersive environments be supported? The overall goal of this thesis is to equip the design and the development teams with the design and empirical knowledge, and unified design tools that support the process of creating immersive interactive storytelling environments.

1.1 Research Objectives

In this section, we formulate the objectives and the research questions that are in the focus of this thesis. The context of each objective is presented as follows:

1.1.1 Design challenges

We aim at creating an immersive and interactive mixed reality environment, which allows the participants to be easily involved and to be able go through the intended storytelling experience without additional learning effort. The design of the interactive features will have to take into account the personal differences of the participants, their previous knowledge and experiences, as well as their short term moods and even their fears from certain settings.

Designing a physically interactive storytelling environments means to choose the *modalities* and to define the interaction features and methods in the context of the story. The most common input modalities are vision, speech, keyboard, touch sensors, and switches. To communicate back to the participant, the environment can use the means of sound, light, and motion. With an appropriate combination of sound design, lighting and visual design, the environment is able to convey emotional messages. In order to define an interactive feature (interface), the modality as well as the flow of the story has to be specified.

We have to identify the *basic factors* and *building blocks* in immersive interactive storytelling environment that influence the user experience. We have to respond on the challenge how to *control and structure* the path through the storyworld and in the same time create "free to explore" interactive environment. In order to address these objectives, we formulate the research question:

Research question 1: *What are the design challenges in the process of design and development of interactive story in mixed reality environment?*

In order to answer this question, design knowledge was acquired from the fields of computer science, interaction design, and psychology to identify the design challenges and the software and hardware requirements. The design challenges were analyzed on three levels: 1) technology; 2) story; and 3) user related challenges. These three groups of design challenges were identified throughout our practical exploration in the ALICE project, the literature review of narrative theories and with a technological state of the art overview of the available technologies and modalities.

1.1.2 Design process

The production of interactive stories in mixed reality environments demands design and engineering efforts that involve a whole group of contributing experts from various fields, like artists, interaction designers, architecture and civil engineers, and software and electrical engineers. A unified design framework would enable the team members with different fields of expertise to develop interactive stories. The problem is that no such consistent set of tools exist for the development of interactive stories in mixed reality environment. We recognize the need to formulate the research question:

Research question 2: *How can the design process be supported by design tools?*

The design process in the ALICE project, allowed us to reflect on the main issues that are encountered during the design and development process. The issues detected in the practical explorations, lead to the requirements for a design tool that would support the design and development process. For this propose we developed the tool *Tell me a Story!*, that was tested in a case study by a group of designers, and the results of the redesign were successfully implemented into the ALICE installation prototype.

1.1.3 User Experience

During the design of immersive and interactive storyworlds there are many design decisions that will affect the subsequent user experience. The empirical knowledge about the factors that influence the user experience can help in the creation of a more suitable storyworld. It is important to gather the empirical evidence about the effects and the influence of certain modalities on the user experience. To address these objectives, we formulate the following research questions:

Research question 3: *What constitutes the user experience in interactive storytelling in mixed reality environments?*

In order to answer this question, we gave a theoretical ground for the research on user experience in interactive storytelling in mixed reality environments. An empirical evidence was collected through two studies conducted in the first three stages of the ALICE installation. In the first study, the results showed that the enriched sound design and the participants' preknowledge of the backstory has significant effect on the presence indicators. The second study explored the effects of different interaction modes, how they influence the behavior of the participant, and their effect on the feelings of agency.

1.2 Methodology

An iterative design approach was followed for the work described in this thesis. Iterative design is commonly used in the development of human-computer interfaces, but also applies in other fields like computer science and industrial design. The design process is based on iterative enhancement to develop a software system incrementally, allowing learning based on earlier, incremental, deliverable versions of the system (Larman and Basili, 2003). In design, usually new artifacts are created within a series of evolving styles. To explain our approach, we use the framework for triangulation across disciplines (Mackay and Fayard, 1997). Triangulation concerns the use of multiple techniques for creating new artifacts.

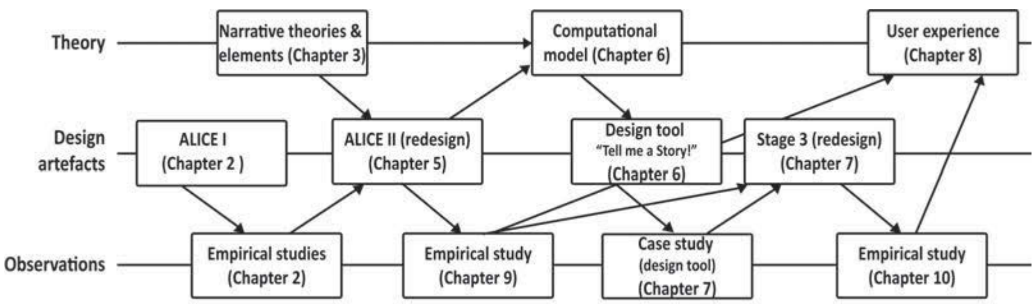


Figure 1.2.1: The research project used in the thesis

The research of interactive environment asks for studying the users, in order to evaluate the technology and to generate design ideas, so we can build better systems. At the empirical level, we can observe how the participants interact with the environment and to develop models of use and to improve the design concepts. At the theoretical level, the interaction models are changed based upon the empirical observations. The design artifacts constantly evolve and influence or change the models at the theoretical level. Figure 1.2.1 provides roadmap of the work described in this thesis, the relevant chapters are also indicated in the figure. The research started with the analysis of the first design artifact - the ALICE I installation and the observations conducted through several empirical studies. The analysis of narrative theories and the knowledge gathered in the empirical studies and practical explorations lead to the redesign of parts of the ALICE

II installation, and to the development of a design tool that can support the storyworld experience design process. Ultimately, with two empirical studies in which more than 100 participants (combined) went through the redesigned installation, we gathered valuable knowledge about the factors that influence the user experience.

1.3 Thesis Outline

The thesis is organized in three parts.

Part I: Background

The first part of this thesis explores the theoretical and practical background for creating an interactive narrative in a mixed reality environment.

Chapter 2 gives an overview of interactive storytelling approaches and the usage of mixed reality environments as a new medium for creating highly immersive storyworlds.

Chapter 3 provides an overview of the established narrative theories, that help us to define the core story elements and their spatial and temporal relations.

Chapter 4 reviews the technological state of the art that allows the merging of real and virtual worlds. An interaction in a physical environment relies on information of what is happening in the physical environment, while an actuation is done in multimodal and multisensory fashion, which involves physical actuation, robotic characters, lighting design, sound, and special effects.

Part II:Design

The second part of this thesis presents the practical explorations of an interactive story in a mixed reality environment. It presents the ALICE project as a case study, and gives an overview of the challenges that arose in the design and development process.

Chapter 5 describes the redesigned ALICE installation with a reflection of the design challenges and solutions. The design process in the ALICE project resulted with inputs for creating a software tool that supports the design and development of similar type of installations.

Chapter 6 describes the developed design tool, named *Tell me a Story!*.

Chapter 7 presents a case study of the usage of the tool and the altered design process.

Part III: Experience

The third part concerns the user experience in an interactive story in a mixed reality environment. Chapter 8 provides the theoretical ground for the main experiential constructs and the factors that influence the user experience in interactive stories.

Chapter 9 and Chapter 10 present empirical evidence about the user experience in the ALICE installation. The first study investigates the effects of sound design and user's preknowledge of the story, when experiencing the redesigned parts of the ALICE installation. The second study examines the effect that the interactivity of the environment has on the user experience and the behavior of the participants.

Part I

Background

2
Interactive Storytelling and Mixed Reality

In this chapter we present an overview of the prominent approaches in interactive storytelling, starting from traditional storytelling, to games, theme parks and digital storytelling. We look into mixed reality as a medium for conveying compelling interactive stories. We review the existing projects that use mixed reality for creating interactive stories. One of the most relevant projects in this direction is the ALICE project that has been active at Eindhoven University of Technology since 2006. It is a collaborative project that involved many researchers and designers through the years. We end the chapter with the presentation of the timeline of the ALICE project, including also the description of the first ALICE installation. We present some of the empirical studies conducted with the installation and reflect on the possible benefits that can be achieved by the installation redesign.

2.1 Introduction

Stories have been imagined, invented, shared and retold by writers and storytellers, in forms of novels, dramas, or moving pictures. We describe the world from an unique perspective and express ourselves with stories, and we try to understand the world around us through stories. Many learning experiences involve stories that are told directly, read and played out. *Narrative* is defined in the dictionary as "a story that is told or written", while *story* is "an account of incidents or events" (Merriam-Webster-Inc., 2004). *Narration* or *storytelling* is a recital of events, usually in a chronological order. Barthes (1988) describes the ubiquity of narratives, "narrative is present in myth, legend, fables, tales, short stories, epics, history, tragedy, comedy, pantomime, paintings, stained-glass windows, movies, local news, conversation". Barthes also notes that storytelling is present in all times, at all places, in all societies: " …like life itself, it is there, international, transhistorical, transcultural".

Over the centuries many different techniques and media have been developed to produce narratives. The oldest stories were conveyed by human voice and acting; later, they were printed on paper; and more recently stories are audiotaped and videotaped for radio and films and stored in a digital form. Digital technology allows interactivity to be implemented between the story material and the audience. Interactive storytelling allows the members of the audience to become active players in the narrative and to have direct impact on the development of the story (Cavazza et al., 2008).

2.2 Interactive Storytelling

2.2.1 Traditional Storytelling

Interactive narrative experiences existed long before digital media. The earliest forms of interactive storytelling are in the from of participatory dramas, rituals, and carnivals. *Rituals* often involve singing, dancing and playing of musical instruments, while participants may use masks and full body costumes. The participants may play specific roles, and their masks and costumes represent important animals, ancestors, and spirit figures.

Interactive theatre is a form of interactive drama that involves the audience. The audience is asked to supply performance suggestions, share the setting, or to become characters in the performance. *Improvisation (Improv)* is an other type of interactive drama where the actors are acting and directing themselves, without previous planning. The plot, characters and dialogue of a game, scene, or story are made up in the moment. Often improvisers will take a suggestion from the audience, or draw on some other source of inspiration to get started.

2.2.2 Games and Theme Parks

The playing of non-digital *games* is also an important precursor to interactive storytelling. Games usually ask for actions and demand physical and mental skills, regulated by specific rules and are clearly structured. *Role-playing games (RPG)* combine narrative with activities where players assume the roles of characters, the actions follow a formal system of rules and guidelines and a game master usually decides on the rules and setting to be used. Players take responsibility for acting out these roles within a narrative, either through literal acting or through a process of structured decision-making or character development. The role-playing games are in a form of board games (tabletop) or *live action role-playing games* (LARP). The first LARPs were run in the late 1970s, inspired by the tabletop role-playing games, where players physically perform their characters' actions.

New technologies have been employed throughout the ages to create compelling story-based environments with realistic imagery and sound, and to increase the user's feeling of physical immersion in stories. The *panoramas* of the nineteenth century were popular entertainment, and are one of the first examples of capturing stories in environments controlled by machines (Oettermann and Schneider, 1997). They consisted of an observation platform surrounded by a painted canvas, which depicted landscapes, battle scenes, and journeys. Mechanical "haunted houses" have populated the carnivals and fairs of the twentieth century. The development of *theme parks* pushed the limits of technology in terms of creating vivid physical renditions of characters and stories, with machines. Disneyland pioneered the use of *animatronic* puppets—sophisticated robotic devices with lifelike movement (Wasko, 2013). These puppets are used to endlessly recreate a physical realization of a story where the characters display a fairly complex set of actions.

The traditional theme park ride lacks interactivity. Visitors exist in the story space, but their actions are never actually reflected in the development of the story or the life of the characters. Although many theme park rides move, shake, and play with the participants' sense of equilibrium, quite commonly, the users' physical activity is severely restricted. Physical interaction is achieved with various novel approaches.

Arcade games have been popular from the 1970's as entertainment machines that have limited ability for interaction. The interaction mechanisms were restricted to usage of a joystick or buttons. Since then the interfaces of arcade games have advanced considerably. Arcade games have more immersive and realistic game controls than either PC or console games, including specialized ambiance or control accessories: e.g., dedicated shaped controllers and dancing mats. Examples include "dancing" games as "Dance Dance Revolution" (Hoysniemi, 2006), the music game "Drum Mania" and light gun shooter games like "Time Crisis", where the games use types of "dance platform" or designed controllers (Blaine, 2005).

Today's theme park designers recognize the potential of interactive experiences, thus they have begun to create new kinds of attractions. A good example of interactive experience is the ride Aladdin (Pausch et al., 1996), developed and tested at Disneyworld, where four users wearing VR helmets loosely control a voyage through a city on a flying carpet. Although most of the user control is restricted to deciding what to see, the presence of the users affects the behavior of the characters in the city. Similarly, "The Buzz Lightyear AstroBlaster" (Trowbridge and Stapleton, 2009) is an interactive ride built around one of the primary characters of the Toy Story films. The ride is highly interactive: the participants can manipulate a "spacecraft" by tilting it and spinning it around in any direction, and can shoot a handheld laser cannon at villains and also against others who are taking the ride at the same time. The ride has a clear *storyline*: the participants play an ally of Buzz on an intergalactic mission. Crawford (2012) argues that the authors of interactive storytelling systems have to build a *storyworld* not a storyline; a storyworld is a much larger creation than a storyline, where a different playing of the same storyworld can generate different stories.

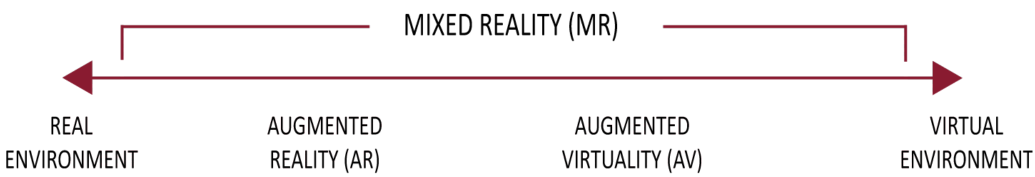


Figure 2.3.1: Milgram's Reality-Virtuality Continuum

2.2.3 Digital storytelling

There is a broad range of ongoing research projects on interactive storytelling that aim towards creating highly interactive stories. Interactive drama has been discussed for a number of years as an artificial intelligence (AI)-based interactive experience (Loyall and Reilly, 1992, Laurel, 1986). Strategies like branching narrative (Gordon et al., 2004, Freeman, 1998), creation of autonomous virtual agents (Aylett, 1999, Theune et al., 2003) and storyworld simulations are applied in interactive storytelling. There is a progress in building believable agents (Loyall and Reilly, 1992, Blumberg, 1996, Hayes-Roth et al., 1997) and interactive plot (Weyhrauch and Bates, 1997). Examples of such systems are: the interactive drama *Façade* (Mateas and Stern, 2003), the emergent narrative *FearNot!* (Aylett et al., 2005), the multi-user tabletop system *The Interactive Storyteller* (Alofs et al., 2012). However, most of these prototypes use virtual reality as a medium, and the interaction mechanisms usually are mouse and keyboard.

2.3 Mixed Reality

Nowadays, *mixed reality* is a form of interactive technology that offers new opportunities for building highly immersive storyworlds. In *mixed reality* environments, digital technology is used in conjunction with physical props and settings to create a variety of experiences. The convergence of sensor networks and virtual worlds allow the real and virtual worlds to function together as a new interactive medium. Participants take part in a physical storyworld and influence the content by being a part of it. These mixed reality environments change the way, in which the story is experienced: the participant can touch, feel, smell, see, hear, and taste in the immersive space. Milgram and Kishino (1994) introduce the concept of the *"virtuality continuum"*, which relates to the mixture of classes of objects presented in any particular display situation (Figure 2.3.1). The real environments, consisting solely of real objects, are shown at the left end of the continuum, and virtual environments without real objects, at the opposite extremum . The real-virtual axis, indicates how much of the constructed world is real and how much virtual. Further, we give definitions for the environments positioned on the real-virtual axis:

Real environment is physical life in the absence of virtual representations of the world.

Augmented reality (AR) has all aspects of reality, plus virtual overlays of information onto real objects. A view of reality is modified by a computer and enhances one's current perception of reality. Augmentation is usually performed in real-time where artificial information about the environment and its objects is overlaid on the real objects. AR technologies (e.g. adding computer vision and object recognition) can make the information interactive and digitally manipulable.

Augmented virtuality (AV) refers to the merging of real world objects into virtual worlds. It refers to predominantly virtual spaces, where physical elements, e.g. physical objects or people, are dynamically integrated into, and can interact with, the virtual world in real-time. This integration is achieved with the use of various techniques, such as manipulation of physical object that reflects the changes in the virtual world.

Virtual environment or *virtual reality* contains only elements generated by a computer and is typically interfaced to with a computer screen and some user input device, such as a mouse or keyboard. Most computer games, and computer applications in general for that matter, fall into this category.

The immersive technologies presented in the reality-virtuality continuum offer many creative opportunities, as the created story elements and the participants are within the same space and may interact with each other.

Stapleton et al. (2002b) introduce an *imaginary reality* (the story) to the "virtuality continuum" to form *mixed fantasy framework* (Figure 2.3.2). Stapleton et al. (2002b) refer to the traditional media: a novel occupies the imagination of the readers, traditional theme park uses the physical reality; whereas storytelling in mixed reality aims to occupy the imagination of the user in mixed reality and to create a compelling immersive experience. They point out that we can use the storytelling process "to heighten the audience's perception, trigger imagination and transcend mixed reality's current limitations."

2.4 The Mixed Fantasy Framework

The relationships between the *components* of storytelling (content, experience and mediator), the *people* (actor, author, audience) who have a critical *role* in each storytelling component and their *goals* (authoring, acting, absorbing) are altered for interactive storytelling systems. In traditional passive media, "the author authors, the actor acts, and the audience absorbs"Stapleton et al. (2002b). The movie theater provides a passive experience and is designed to designate the body of the spectator, i.e. it utilizes comfortable seating, surround sound and a large screen. The movie theater overwhelms the audience with one-way communication that does not involve interactivity. Mixed reality and interactive storytelling aim to blur the boundaries between the author, actor, and the audience. Experiential media such as theme parks, video games, and mixed

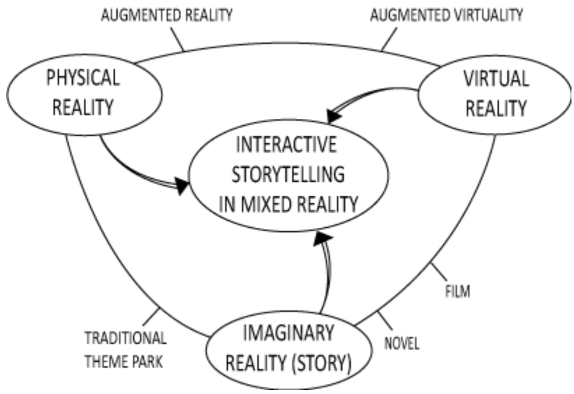


Figure 2.3.2: Mixed-fantasy framework (Stapleton et al., 2002b)

reality installations are designed to engage the participant's body and mind in the physical world. To realize interactivity, a system also has to observe and interpret the actions of the participant and to respond to them in meaningful ways.

Table 2.4.1: Extended Reality-Medium comparison matrix (Stapleton et al., 2002a)

	Book	Film	Theme park	Video game	ISVR	ISMR
Reality (World)	Home	Mall	Location based	Store	Home	Location based
Display (Venue)	Home	Cinema	Theme park	Arcade	Computer	Immersive storyworld
Audience (Activity)	Read	Watch	Respond	Interact*	Interact*	Interact**
Author (Convention)	Novel	Feature film	Ride show	Game	Interactive drama	Interactive storyworld
Media (Device)	Print media	Optical print	Actors scenery	Virtual reality	Virtual reality	Physical storyworld
* mouse, keyboard, devices **move, touch, gesture						

In the entertainment industry, the imagination of the audience is considered a critical element, while technology (virtual reality, print media or optical prints) is viewed as a means to spark the imagination. Stapleton et al. (2002a) refer to the Reality-Media continuum to address the transformation of the ordinary world into a virtual world of fiction and fantasy. We add interactive storytelling in virtual (ISVR) and mixed reality (ISMR), to the Reality-Medium comparison matrix (see Table 2.4.1). Interactive storytelling in virtual reality can use different type of displays, such as Cave Automatic Virtual Environment (CAVE), Head Mounted Displays (HMD) or a screen. In the comparison matrix, we refer to ISVR available in the home, where interaction means are control devices, such as mouse and keyboard. Interactive storytelling in a mixed reality environment implements interaction that involves the physical world. Movement, touch and gesture are used to interact with the content of the story.

2.5 Related work: Mixed reality installations

A number of research projects attempt to create rich user experiences in mixed reality environments. The applications of mixed reality environments range from museum exhibitions, military training spaces, to games and interactive storytelling environments.

2.5.1 Games, Museums and Exhibitions

There are many attempts to develop mixed reality environments that will convey engaging and compelling user experience. By using the existing technologies various places may be transformed into platforms and playgrounds that aim to entertain, motivate and inspire. Games are usually goal-directed, structured play experiences (Bonsignore et al., 2012) which use a physical, real world environment and the physical context of the user influence's the game play. Such projects are using the physical and social aspects of a game play. "Touch-Space" provides a full spectrum of tangible game interaction experience ranging from the real physical environment (Cheok et al., 2002). Jones et al. (2014) present proof-of-concept prototype, RoomAlive, which enables new interactive projection mapping experiences that transform any room into an immersive, augmented entertainment experience, where users can touch, shoot, stomp, dodge and steer projected content that seamlessly co-exists with their existing physical environment. Projection-based augmented reality in Disney parks is presented in Mine et al. (2012), in the interactive applications such as "The Storytellers Sandbox" and "Goofy's Paint 'n' Play House" attraction.

The Media Convergence Lab at University of Florida researches the development and applications of mixed reality environments. Hughes et al. (2005) present the museum Sea Creatures experience, which vividly alters a physical setup with an augmented scenery from an underwater world. The MR for Military Operations in the Urban Terrain project, uses an extreme and complex layered representation of combat reality, using all the simulation domains such as live, virtual, and constructive by applying advanced video see-through mixed reality technologies. Hughes et al. (2005) note that to transform technical capabilities of emerging mixed reality technology into the mainstream involves the integration and evolution of unproven systems, which involves content, production, technical and business issues. They discuss the production and delivery tools, also claim that the success of mixed reality "will come about not only by advancing technological capabilities, but also by exploiting creative possibilities."

2.5.2 Interactive Storytelling

In difference to the above mentioned projects, interactive storytelling aims to put the *story* in the middle of the context development. One such example of an augmented reality interactive drama is AR Façade (Dow et al., 2006), based on the desktop-based interactive drama Façade (Mateas and Stern, 2003). The participants are engaged in interaction with virtual characters while they move inside a physical apartment. The AR Façade project initiates questions about the challenges of building the environment, designing a mixed physical/virtual interaction and how all of this influences the behavior of the participants and their experience. Another artificial intelligence (AI) based interactive storytelling game (Cavazza et al., 2003), engages the users in a physical deck while playing the part of James Bond and uses gestures recognition and spoken utterances to converse with the virtual actors.

MIT Media lab presents several projects in physically interactive story environments: KidsRoom, It/I, Personal Aerobics Trainer, and Swamped! (Pinhanez et al., 2000). The environments are based on complex sensory mechanisms designed to make the interaction as natural as possible; the interaction is not based on explicit mechanisms but with implementation of responsive characters and environments. Pinhanez et al. (2000) conclude that using unencumbering, rich sensor technology can facilitate user immersion in the experience as the story progresses and compelling interactive narrative story systems can be perceived as highly responsive, engaging, and interactive even when the overall story has a single-path structure.

These projects are applying the immersive capabilities of mixed reality to engage the users in different type of settings. Each of them implements various interaction mechanism and techniques for augmenting the physical environment. AR Façade and KidsRoom are examples of engaging participants in a development of a story in a augmented environmen, and show the potential for using mixed reality for creating interactive stories.

The potential of mixed reality for creating interactive stories is huge. However, there are still not many mixed reality installations that will allow practical explorations in a such interactive storytelling environment. For this research, we used the ALICE project as a testbed that allows us to explore interactive storytelling in mixed reality. In the following, we will present the motivation for building the ALICE installation, the technical implementation of the first ALICE installations, with an overview on the timeline and the involved parties.

2.6 The ALICE project

The ALICE project(Rauterberg, 2006c) aims to provide an experimental platform for research and design questions regarding the user experiences within immersive mixed reality environment. It implements an immersive mixed-reality installation based on the narrative "Alice's Adventures in Wonderland" by Carroll (1865). The ALICE project is conducted at the Designed Intelligence Group of the Department of Industrial Design, Eindhoven University of Technology (TU/e). It is supported by Microsoft Research in Cambridge (UK), and the departments of Industrial Design and Electrical Engineering of TU/e.

2.6.1 Cultural Computing and Interactive Storytelling in Mixed Reality

Cultural computing is a new human-computer interaction paradigm that aims to provide an interactive experience that is closely related to the core aspects of a culture (Kooijmans and Rauterberg, 2007). The user is engaged in experience that uses the values and attributes of her own culture. Cultural computing aims to address underlying and almost unconscious cultural determinants that have since ancient times a strong influence on our ontology and epistemology (Rauterberg, 2006c).

Different cultures worldwide will have different approaches to address their particular cultural determinants. Rauterberg (2006c) discusses the importance to understand one's cultural determinants and how to render them during an interaction. Rauterberg introduces new research challenges, such as: (1) what are the relevant cultural determinants in different cultures to enable the user to transform herself towards enlightenment (Salem and Rauterberg, 2005); (2) what kind of interactive experiences will have the most supportive potential regarding this transformation (Nakatsu et al., 2005); (3) what are the differences between cultures worldwide and how to address them; and (4) how to measure the effects regarding the progress achieved in transforming oneself (Rauterberg, 2006b).

"Alice's Adventures in Wonderland" by Lewis Carroll (1865) is recognized as a very appropriate narrative to investigate logical reasoning in the western culture. Rauterberg (2006c) proposes that the book "Alice's Adventures in Wonderland" can serve as input for a cultural computing project in the West; and suggests that it can be used to give interesting examples of many of the basic concepts of adolescent psychology. Lough (1983) argues that Alice's experiences can be seen as symbolic depictions of important aspects of adolescent development, such as initiation, identity formation, and physical, cognitive, moral, and social development. Alice's adventures are deconstructivist in nature and as such are directly challenging the strongly held belief of a linear, single track and sequential reality.

The ALICE project was started as a promising candidate for researching interactive experiences that address the cultural determinants of the Western world. In the ALICE project, interactive adventures are provided by a mixed reality environment. The user assumes the role of Alice and explores this interactive narrative through virtual and real locations, moral choices and emotional states. Rauterberg (2006c) describes the ALICE installation as follows: "The narrative is a surreal quest, sometimes funny, sometimes disturbing. ALICE is an educational journey towards the user's heart's desire, designed to provoke self-reflection on a number of other issues: bullying and trusting others; selfish- and selfless-ness; enjoying the moment or sublimating pleasure. The user is given the opportunity to occupy and experience any of these mental and emotional positions." This description is comprises the objective for the design of six separate stages of the ALICE installation. In the next section we will describe the technical and design challenges in the ALICE project.

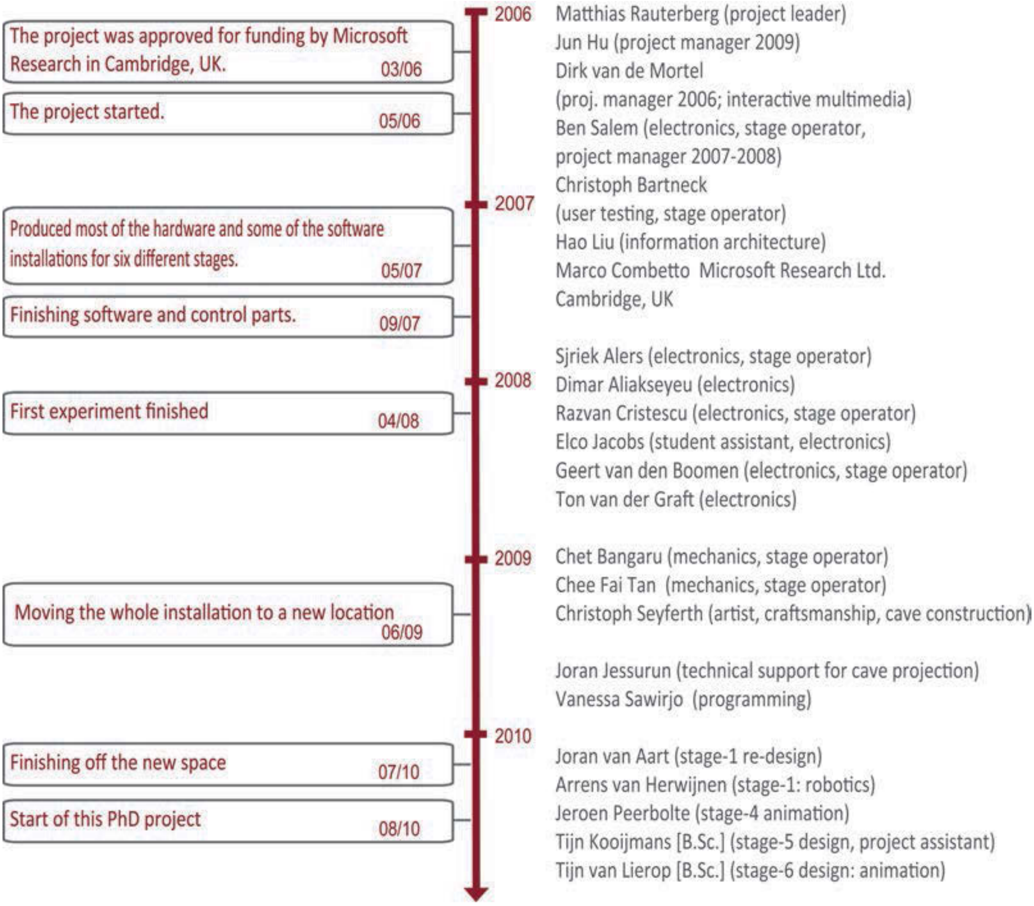
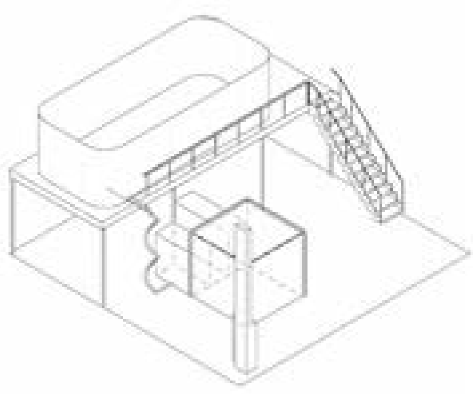


Figure 2.6.1: A timeline of the ALICE project (ALICE I), important events (left) and involved researchers, experts, technicians and designers (right).

2.6.2 Timeline and design team

The ALICE project was used as a testbed and research playground for the last several years (2006-2014). Figure 2.6.1 shows the timeline of the ALICE project. The project started in May 2006, the first installation was built until end of 2008 and initial experiments were done until end of 2009. The installation was rebuilt at a different location starting from June 2009. This PhD

(a) W-hal building at the TU/e campus, containing the Alice installation



(b) Schematic drawing of the two floors installation inside the building

Figure 2.6.2: The Alice installation

project started in August 2010. The moving of the installation asked for complete rebuilding of the physical space and re-installation and redesign of the technical components.

During this whole period (2006-2014), the ALICE project has involved many researchers and designers that contributed to the creation of the installation and conducted research related to the system (technological objectives) and to the user experience (socio-cultural objectives). In Figure 2.6.1 at the right side is a list of the researchers and experts involved in the ALICE project. On the right side of the figure is the long list of technicians that were involved in the building of the installation and experts that controlled the safety of the installation.

An iterative design approach was used throughout the refining of the design of stages and interaction features in the storyworld. Starting from the novel "Alice's Adventures in Wonderland" Carroll (1865), the first decisions were made regarding the implementation of the storyworld. The first design team brainstormed about the possible implementation of the story scenario, and the technical means, the user experience and research challenges. In the first installation, prototypes were produced and several pilot test and empirical studies were conducted. However, the interactive story scenario was not connected into an automated holistic experience nor tested as such. The installation had to be removed due to renovation of the building where it was located, and had to be rebuilt on a new location. For the second installation, the design team took into account the already produced prototypes and concepts, reflected on the conclusions from the conducted empirical research and the technical and design challenges. Next, we describe the first ALICE installations built at TU/e.

2.6.3 The First ALICE Installation

The first ALICE installation was built inside of the W-Hal building of TU/e, in the period from March 2006 to March 2008, see Figure 2.6.2. The installation took a space of 12 by 12 meter spanning two floors over a total height of 7 meters. Figure 2.6.2b shows a schematic drawing of the installation. In this section we will provide a technical description of the installation, including the mixed physical/virtual reality stages and a short description of the underlying technology and the intended experience. Detailed information about the first ALICE installation and the separate stages is available in the publications: Bartneck et al. (2008), Hu et al. (2008), Kooijmans et al. and Nakevska et al. (2012a); the conducted empirical research is published in: Aart et al. (2010), Kooijmans and Rauterberg (2006, 2007), Rauterberg et al. (2010), Rauterberg (2006a) and Rauterberg (2006b).

2.6.4 Narrative

During the initial brainstorming, several chapters from the narrative "Alice's Adventures in Wonderland" by Carroll (1865) were chosen for implementation. Here we give their short summary:

> CHAPTER I: Down the rabbit hole. *Alice was beginning to get very tired of sitting by her sister on the bank, and of having nothing to do. The possible activities around her are not very appealing. Suddenly she notices a White Rabbit with pink eyes and a pocket watch, which ran close by her and says to itself 'Oh dear! Oh dear! I shall be late!'. Alice is very curious to follow the White Rabbit, since she has never seen such rabbit. She sees how the rabbit pops down a large rabbit-hole under the hedge. Alice goes after the rabbit, she has no time to think about stopping herself before she finds herself falling down a very deep well. She has a lot of time to fall, so she has plenty of time to look about her and to wonder what was going to happen next. She contemplates the possibilities where she will end up. She falls down on a ground and she notices a long passage in which she sees the White Rabbit hurrying down it. She finds herself in a room with doors all round the hall, and she notices that they are all locked, she tries every door and she wonders how she was ever get out again. On a small glass table she finds a tiny golden key, the tries it all around and finally she finds a small door behind a curtain. She opens that door and sees that it leads into a small passage into a lovely garden. She longs to get out of that dark hall and to go to the beautiful garden, but she can't go through the door. She goes back to the small table and now she finds a bottle with a label saying 'Drink me'. She looks if it is marked as poison and if it is safe to drink it. When she drinks it, she becomes very small, the right size for going through the little door. But she noticed that she left the key on the table and she can not reach it. She notices a glass box that lays under the table, with beautifully marked words 'Eat me'. She wonders about the effect of this, and she decides to eat the cake...*
> CHAPTER II: The Pool of Tears. *Alice becomes very big, which makes her hopeless*

about her exit through the garden. She cries many tears, finally she gets the key, she becomes small again and is able to go out. Now she swims trough a sea of her tears. She notices a mouse and she interacts with it.
CHAPTER V: Advice from a Caterpillar. *After Alice is engaged in conversations with several characters, she finds the large caterpillar which sits on a big mushroom. The caterpillar asks Alice about herself, and she talks about the confusions that come out of the previous experience.*
CHAPTER VI - Pig and Pepper. *On this journey, Alice meets many other creatures, and one is the Cheshire cat which could change itself and to disappear completely. The Cheshire cat engages Alice in conversation about madness and logic.*

Table 2.6.1: The six stages from the ALICE installation (theme, experience and possible measurements) (Hu et al., 2008)

Stage	Theme	Experience	Measurements
1 In the park	Time	Boredom and curiosity	Retrospective duration
2 Down the rabbit hole	Environmental space	Disorientation	Presence
3 Eat Me, Drink me	Personal space	Shrinking and growing	Presence
4 The pool of tears	Genesis	Swimming, out of water	-
5 Advice from a caterpillar	Self	Questioning the concept of self	Personality, self esteem and concept
6 Cheshire cat	Logic	Challenged by the logic reasoning	Generating alternatives

From these chapters and sub-chapters, six consecutive stages were built. Chapter I from the novel was used as an inspiration for three stages in the installation: Stage 1 "*In the park*", Stage 2 "*Down the rabbit hole*" and Stage 3 "*Eat me, Drink me*". The described part of Chapter II was inspiration for Stage 4 "*The pool of tears*", also the described parts from Chapter V and VI inspired Stage 5 "*Advice from a caterpillar*" and Stage 6 "*Cheshire cat*". Hu et al. (2008) explained the Alice's adventures in six stages, and how each stage aims at particular aspect of the user experience (see Table 2.6.1). Further, we will give a short description of the implementation of each stage.

2.6.5 Stages

Stage 1: In the park. The visitor of the ALICE installation enters this stage through two curtains. A panorama picture printed on a large fabric, depicts a location in nature (Figure 2.6.3). A physical rabbit that is mounted on top of remote controlled car, appears from behind the curtain. A researcher observes the room through a surveillance video camera and controls the movement of the rabbit.

(a) Following the rabbit **(b)** Entering the rabbit hole

Figure 2.6.3: A participant in Stage 1: "In the park"

Stage 2: Down the rabbit hole. The user enters the "rabbit hole". There is an electric seat is mounted on a rail. To ensure safety in this installation, a gate is mounted on the entrance of the vertical tunnel, which is opened when the user is safely seated and the armrests are down, the gate is opened and the chair moves down (Figure 2.6.4a). Along the walls of the tunnel, cupboards, bookshelves and lamps are mounted. The electric seat goes down in a spiral movement (Figure 2.6.4b). Infrared cameras are placed inside the rabbit hole to allow the experimenter to monitor the visitor.

(a) At the entrance of the rabbit hole **(b)** Descending through the rabbit hole

Figure 2.6.4: A participant in Stage 2: "Down the rabbit hole"

Stage 3: Eat Me and Drink Me. This stage was implemented into a cubic CAVE (Cruz-Neira et al., 1992) made of white semi-transparent material. A sliding side is connected to the entrance and the exit tunnels, enabling a 5-side full projection when the visitor is in the CAVE (Figure

2.6.5a). The Vizard VR Toolkit from Worldviz is used to synchronize the five projections. A cookies box labeled “Eat Me” and a bottle labeled “Drink Me” are placed on top of a small table (Figure 2.6.5b).

(a) The virtual room

(b) “Eat me” and “Drink me”

Figure 2.6.5: Stage 3: “Eat me, Drink me”

The mechanisms in Stage 3 are described in Hu et al. (2008): “When the visitor drinks from the bottle, the virtual room enlarges, giving the impression that the visitor is shrinking. When eating the cookie, the virtual room shrinks, giving the visitor the impression that she is growing. The floor of the cave is equipped with pressure sensors that allow us to determine the visitor’s position in the CAVE. Depending on her location, the perspective of the projection is adjusted to give a true 3D impression of the virtual room. The bottle features touch and tilt sensors to detect drinking. The cookie box is equipped with a microphone that allows us to detect the visitor’s chewing sounds when eating the cookie.”

Stage 4: The Pool of Tears. Stage 4 consists from a projected virtual scene that is enriched with a fog machine to create an impression of moisture (Figure 2.6.6a). The projected scene depicts a mouse which swims in a sea. The produced fog creates a mystical feeling to this stage. The visitor walks along the projection and thereby enters stage five.

Stage 5: Advice from a Caterpillar. Stage 5 features a dialogue with a robotic caterpillar that engages the user in a similar dialogue as the one in the book (Figure 2.6.6b) (Kooijmans and Rauterberg, 2006). Hu et al. (2008) explain: “Microphones recorded the utterances of the visitor and a simple dialogue system manages the conversation. Since most of the questions are metaphysical or mystical, a conclusive dialogue can be created without extensive AI for the caterpillar.”

Stage 6: The Cheshire Cat. Stage 6 is also a dialogue, this time with a Cheshire cat which changes it shapes and sometimes disappears. A virtual Cheshire Cat that is projected on a screen (Figure 2.6.7) engages the user in a dialogue similar to the one in Carroll’s book. Similarly as in

(a) The pool of tears

(b) A participant talking to the caterpillar

Figure 2.6.6: Stage 4: "The Pool of Tears" and Stage 5: "Advice from a Caterpillar"

Stage 5, Hu et al. (2008) notice: "most of the questions are metaphysical or mystical, and hence a conclusive dialogue can be created without an extensive AI."

2.6.6 Empirical Studies, Reflections and Motivations for Redesign

Several empirical tests were performed in the separate stages and the whole installation. Bartneck et al. (2008) assumed: "the visitors' experience may range from being mildly entertained to a deeper psychological disturbance." The users were expected to play the role of the character Alice and experience the sequence of emotional and behavioural states in the same manner Alice did in her quest. Bartneck et al. (2008) noticed that "it is likely that the ALICE installation will have an effect on its visitors, but it is unclear what effects and how strong they may be" (Bartneck et al., 2008).

A couple of research studies addressed the effects of the separate stages in the ALICE installation. The assessment and measurement of the user experience in this type of environment were discussed by Rauterberg (2006a). Kooijmans and Rauterberg (2007), used an "implicit association test" (IAT) to measure significant difference between a subject's self-concept before and after the experience in *Stage 5 "Advice from a Caterpillar"*. They concluded that the experience in the ALICE installation will have a unconscious effect towards individual metamorphosis (Kooijmans and Rauterberg, 2007).

Another study was conveyed in *Stage 1 "In the park"*, to address boredom and curiosity as drives for the behavior of the user. Aart et al. (2010) conducted an empirical study on the users' behavior in this stage and demonstrated that "particular sequence of events has a significant positive influence on the arousal of curiosity and on triggering and guiding intended user behaviour."

Figure 2.6.7: Stage 6: transformations of the Cheshire Cat and a participant talking with the Chesire Cat

Hu et al. (2008) noted "it is a challenge of its own how these software and hardware bits and pieces can be structured together into one automated system that brings the visitor a smooth and holistic experience." They explored the possibilities for implementing multi-layered agent based structure based on a distributed architecture. Their proposition was to implement a three-layered structure. However, in the first ALICE installation most of the interaction mechanisms were implemented as Wizard of Oz (WOz) techniques. Pilot experiments through six stages involved at least three stage operators. Although separate stages implemented their own sensing and actuation mechanisms, they were not integrated in one coherent automated story. The installation had to be rebuilt to a new location in 2009, due to change in available space at TU/e. Hence, these design and technical challenges and redesign of the interactive story scenario were done in the second ALICE installation.

3

Narrative Theories and Elements

In this chapter, we will review several narrative theories that help us to identify the fundamental concepts of interactive storytelling in mixed reality and to derive formalisms for practical implementations of interactive stories. We recognize the core narrative elements, such as characters, spatial settings, actions and events, and the spatial and temporal relations among them. Finally, we review the established strategies and approaches for structuring interactive stories.

3.1 Narrative Theories

There are diverse narrative theories that describe the structure of drama, screenplays and films. Structuralism in narratology is the approach to analysing a narrative material by examining the underlying structure. The narrative structure is described in terms of parts, acts and narrative units.

The first to describe narrative structure is Aristotle (330 BC), describing the nature of tragic drama in three defining respects: objects, medium, and manner. He lists six parts which determine the quality of tragedy: Plot, Character, Diction, Thought, Spectacle, Music. *Plot* refers to the action being imitated in each performance of drama; *Character* is a bundle of traits predispositions and patterns of choice; *Thought* is the internal process of leading choice(cognition, emotion and reason); *Diction* refers to the selection of language, arrangement of words; *Music* and *Spectacle* refer to everything that can be heard and seen.

Freytag (1872) divides a drama in *five parts or acts*: exposition, rising point, climax, falling action, and resolution (see Figure 3.1.1). The *exposition* is the portion of a story that introduces

Figure 3.1.2: Chatman's diagram of the narrative elements (Chatman, 1980)

important background information to the audience; in the *rising action* a series of related incidents build toward the point of greatest interest; the *climax* is the turning point; during the falling action the conflict unravels; *dénouement* or *resolution* comprises events from the end of the falling action to the actual ending scene of the drama or narrative.
Based on the Aristotle's theory Field (1994) outlines a *three-act paradigm*, followed by most screenplays. Field argues that the story is made of: the action, characters, scenes, sequences, incidents, episodes, music, locations; and every screenplay has a beginning, a middle and an end.

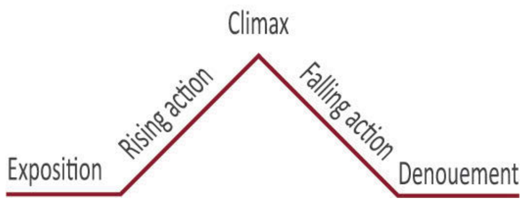


Figure 3.1.1: Freytag's five act structure (Freytag, 1872)

Vladimir Propp's morphology of Russian tales is another approach to compare structure of various narratives. Propp (1968) considers the narrative as a logical sequence of *actions*, each action possessing a set of *functions* relative to the narrative. Propp derived a clear distinction between variable and constant elements of the fables. He reduced the narrative structure to a sequence of sufficient functions for describing a story. Propp suggested a seven-part model, which can have all or a subset of the functions, and the ordering must not change.

Barthes (1966) analysed further the trans-historic and cross-cultural stories. He identified three hierarchical levels of narrative: functions, actions and narratives. The narrative can be decomposed into *narrative units*; each unit has a different function in the narrative, which is described by associating a type to each unit.

Chatman (1980) examines the narrative structure in fiction and film and divides narrative into two parts: *what(story)* and *how(discourse)*, see Figure 3.1.2. Story is the content, consisting of events and existents (characters and setting). The elements of discourse thus determine how certain effects are achieved. Chatman distinguishes *story-space* from *discourse-space*: the *story-space* contains existents, which can be represented in different ways in the *discourse-space*. The *story* consist of *events* (actions, happenings) and *existents* (characters, settings). The events in a story are turned into a plot by its discourse. The plot starts from a certain situation or state of affairs and often moves through *space* and *time*.

Interactivity

Interactivity in a narrative requires an adaptation of the existent narrative theory to suit the user actions and interaction within the plot. Laurel (1986) adopts the Aristotelian framework for interactive drama by defining the corresponding elements: *Plot*(the whole action that is interactively shaped), *Diction*(the selection and arrangement of discursive signs, including visual, auditory, and non-verbal signs), *Character*, *Thought*, *Music* and *Spectacle* are same as in a drama, but including the user as well as fictitious agents.

Laurel employs the casual analysis introduced by Aristotle (330 BC), to define the relationships among the structural elements. When elements are hierarchically organized with plot on the top, and the spectacle on the bottom, it defines the *material causality* and the *form causality*, see Figure 3.1.3. The *material cause* of something is the material out which it is constructed, while the *formal cause* of something is the abstract plan, goal, or ideal toward which something is heading.

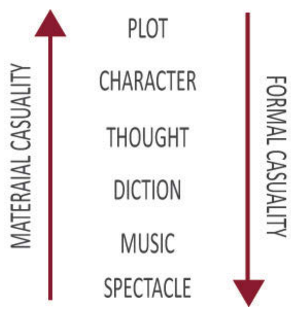


Figure 3.1.3: The forces of material and formal causality (Laurel, 1986)

Murray (1997) proposes three aesthetic categories for the analysis of interactive story experience: immersion, agency, and transformation. *Immersion* is the feeling of being present in another place and engaged in the action therein; *Agency* is the feeling of empowerment that comes from being able to take actions in the world whose effects relate to the player's intention; *Transformation* is defined by three meanings: transformation as masquerade (the game experience allows players to transform themselves into others for the duration of the experience), transformation as variety (the experience offers a multitude of variation on theme) and personal transformation (the experience takes players on journey of personal transformation).

Mateas (2001) concludes that from the interactive dramatic perspective, agency is the most fundamental of Murray's three categories. Mateas introduced the *neo-Aristotelian theory*, by adding interaction to the Aristotelian model. Two new casual chains are added at the level of character, the user is added to the model as a character who can choose her own actions, see Figure 3.1.4. The *user's action* is situated at the character level in the Aristotle's narrative structure. The elements presented as material resources provide the user with material for taking action and the user's intentions are a new source of formal causation. By taking action in the interactive experi-

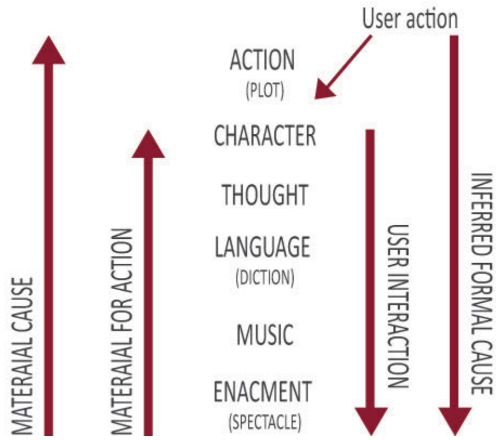


Figure 3.1.4: The Neo-Aristotelian theory of drama (Mateas, 2001)

ence, the user's intentions become the formal cause of activity. The material affordances refer to having many things to do, while the formal affordances are giving the context of why any action would be preferable to another.

3.2 Narrative elements

One of our main research objective is to *Identify the design challenges in the process of design and development of interactive story in mixed reality environment.* This research objective relates to identifying the *basic factors* and *building blocks* that influence the user experience. Once the designer know the type of building blocks that will be using, the core content of the material world can be determined, together with places where the user can make a choice or perform an action.

The presented narrative theories give a guideline for identifying these building blocks. Chatman's narrative theory gives clear structure for defining the building blocks of a narrative. In the literature review, we presented also other narrative theories. For instance, the five acts paradigm (exposition, rising point, climax, falling action, resolution)(Section 3.1), which ensures a compelling structure in a drama. Such narrative structure would contribute to the feeling of suspense and engagement in the narrative. Several research projects of interactive storytelling in virtual reality, take in consideration cognitive models (Szilas, 2002), perceptual models (Szilas, 2003), emotional planning (Cavazza et al., 2009), and models for artificial intelligence (AI) planning algorithms (Young, 1999). It is valuable to consider such extended models. But, since we deal with more complex immersive environment, we are interested to implement a simple structure of the interactive narrative.

We consider two important layers necessary to build a narrative in mixed reality: story space and discourse space. The *story space* gives the conceptualization of the storyworld with the core story elements (existents and actions). The *discourse space* gives the structure and spatial and temporal interdependencies between the story elements. One story can generate various discourses, depending on the realization and scheduling of the events/actions from the story. In interactive narrative, each user can take a different discourse through interaction and produce new *scenarios*. A *scenario* is the set of possible discourses of a story. The changes of the story are creating new scenarios. In the reminder of this chapter, we will describe the *story content*, the story-existents: *characters* and *spatial settings*; also the *actions* and *events* and their *temporal* and *spatial relations* that structure an interactive storytelling experience in mixed reality.

3.3 Characters

The events in a narrative happen or are triggered by someone or something. These actions of the plot usually require *agents*. Agents in a narrative may be humans or animals, or creatures, or an instrumental agent that performs actions to explain the narrative purpose (Chatman and Attebery, 1993). The *characters* are agents that stretch beyond the actions; they posse traits, motives, and personality. They are an essential element for storytelling. They give life to the narrative as they perform actions, make choices, and interact with the setting. The characters can enrich the setting with their presence and engage the participant in the mediated environment by adding humor, obstacles, or challenges for the participant.

The participant may join the interactive story as one of the characters in the story. In some interactive narratives, the participant is assigned to a particular role (e.g. detective, hero) at the very beginning. Another possibility for the participant is to play herself, while interacting with fictional characters and events. The characters of a story can serve specialized roles, as they offer assistance to the participant, answer her questions, or introduce the participant with the mediated world to make her feel invited and safe. The characters with their personality and actions can easily portray emotions, and induce the user to experience strong feelings (Bowen, 2005, Murray, 2005).

It is important to employ more deep and more interesting characters to populate the story world, so the participants will feel motivated to interact with them (Sheldon, 2004). Mixed reality offers a broad range of possibilities for creating characters in an interactive storyworld. A character in the story can be embodied into an autonomous robotic agent, or a three-dimensional VR agent that portrays certain behavior, or it can be an abstract form that is represented by sound and special effects.

The process of creating characters in a narrative is called *characterization*. It is a literary element that is also adapted in game design. In a verbal narrative, *characterization* is the process which gives traits to the characters. Lankoski et al. (2003) conclude that characterization in interactive computer games is a similar process as designing a character as in other linear media. Lankoski et al. divided the methods of building characters in computer games as: 1) building pre-defined functions of the character; 2) setting the goals of the game; 3) choosing and implementing possible and impossible actions; and 4) characterization. A character is built by designing the observable aspects into physical abilities and features. Both physical abilities and features are often linked with the definition of pre-defined functions like gestures and movement, which contributes to assigning personality traits to the character. The visible features are used to indicate possible actions and intentions, turning the character into a potential for action.

Authors convey information about the characters in games by using appearance, dialogue and actions as sub-tools for characterization (Margolin, 1983). The *appearance* can communicate useful information to the participant, such as age or gender. The *dialogue* allows the characters to speak for themselves. The way in which characters say something often reveals information about them or the situation. The *actions* of the characters also reveal the personality of the character and parts of the story plot. In the process of creating characters in mixed reality environments, authors need to consider a broad range of possibilities in implementing the features of a character, through its actions and appearance. The interaction in the physical world that does not involve standard input devices also imposes novel technical challenges. Physically interactive narratives would also ask for implementation of specific sensing mechanisms. There are a number of research projects (Breazeal et al., 2003, Bruce et al., 2000, Loyall and Bates, 1997, Dow et al., 2010) that have explored the use of speech recognition and dialogue systems to allow people to have simple verbal interactions with robotic performers and to have simple "improvisational" dialogue. We will deliberate further on these technical challenges in Chapter 4.

Characters are an essential element of all forms in storytelling. They are also very important in interactive storytelling, since they are the basic element for implementing interaction. Interactivity makes it more difficult to construct complex characters. The presented techniques reveal part of the design challenges in building characters in an interactive narrative. Designers may use the presented techniques and tools in order to build characters. There are many other approaches that can be taken, such as constructing character arc, creating emergent and emotional behavior models (Freeman, 2004, Louchart and Aylett, 2004).

3.4 Spatial Setting

Besides characters and agents, a fictional world contains *places* and *objects* appropriate to the story plot. Chatman and Attebery (1993) name these places - *settings* and the objects - *props*: "*setting* is the larger backdrop against which the events transpire, *props* are the objects handled or otherwise encountered by the characters." Setting contributes to climates of emotion and attitude; the word *atmosphere* is used to refer to such climates, to the tone or mood of a narrative (Chatman and Attebery, 1993). *Atmosphere* of a physical space is "everything that we encounter when we enter a space"; *mood* is the result of the effect that atmosphere and space has on people (Lukas, 2012). The choice of setting and props is crucial to support the story plot and to convey the intended atmosphere.

Staging is one of the most important aspects of bringing drama to film and theater plays. To create a stage, the director uses construction materials, lighting, and technology. To transfer a story from one to next space, in film-making techniques like edits and cuts are used. In theater usually there is one scene, thus choices have to be made which elements to include and which to leave out from the scene. Space and architecture supports the story with visual elements and should convey the same message as the scenario of the story. Disney theme parks use architecture to tell a story: "each building foundation not only supports a physical structure, but also supports a story structure." Imagineers (1996) state: "Imagineering buildings are not simple structures or studio facades, but whole events. They are illustrated book covers leading to the stories that await inside. Creating a sense of time, place and mood, Imagineered architecture can, in a single instant, transport you to a distant land." Theme park designers have come up with useful solutions on how architecture and design can be used to lead visitors through an experience. Alexander (2014) explains that theme entertainment projects are very different than usual architecture: "...you are creating a "show", a three dimensional movie you can smell and feel. The architecture can be seen as the "stage" upon which the "show" is performed."

3.4.1 Design Elements and Principles

Hench et al. (2003) introduced color as a powerful storytelling element in theme parks; they explain how color helps storytelling in theme parks: color supports story structure, establishes mood, enhances the illusion of reality, and supports special effects. For example, Imagineers use colors to visualize one building next to another. Each attraction has a color scheme and identifies the story clearly.

Similarly, other elements of design that are applied to a space and can contribute to the holistic experience are: *shape* (a self contained defined area of geometric or organic form), *line* (directional properties like horizontal or vertical, curved or straight), *texture* (feel and appearance of a surface: rough, smooth, soft, hard), *size* (physical extend or magnitude of an object), *scale and proportion*(size relationships between objects) (McClurg-Genevese, 2005).

In addition to these elements of design, there are some principles of design that can be applied. Evans and Thomas (2012) define the fundamental principles of design and divide them on primary and supporting ones. The primary principles affect the design as a whole, while support principles affect the internal relationships of a design. The design principles include the following (Lukas, 2012, Evans and Thomas, 2012):

- *unity:* creates an integrated image in which all the elements are working together to support the design as a whole; it refers to a unified design that has been applied to all the elements within the space.
- *variety:* complements to unity and is used to create visual interest. It refers to a way of combining elements, often is obtained through the use of diversity and change.
- *repetition:* reusing of the same or similar elements throughout a design.
- *contrast:* refers to the arrangement of opposite elements (light vs. dark colors, rough vs. smooth textures, large vs. small shapes, etc.) Contrast is a way to add variation in the space and to create visual interest, excitement and drama.

- *hierarchy:* refers to the order in which the elements within a composition are viewed. Hierarchy achieves order of importance, e.g. with *placement*, as an object placed in the center will often be perceived as a focal point or an element in *contrast* with something else is more easily seen and understood.
- *proportion:* refers to the size relationships within a composition, it can be between objects, or parts of a whole.
- *harmony and balance:* creates equal distribution of visual weight in a design. Harmony combines previously mentioned elements like color, shape and texture, e.g. similar colors or shapes. Balance is the visual distribution of elements in a composition.
- *emphasis:* creates a focal point in a design and brings attention to what is most important. Often one or more elements can be *emphasized* through combinations of color, texture or placement, which can orient the movement of the users within the space. Disney theme parks use a design feature known as "*weenie*", that draws the visitors' attention as a goal or a landmark (Disney and Eisner, 1996).

Theme parks often use techniques such as: forced perspective, over-sized props, landscaping elements, and detailed material elements (Alcorn, 2010). A scenery can incorporate *landscaping elements* like rocks, dirt, bushes, trees. Natural materials are used like wood, metal, cloth and paint to make the setting more believable and involving. The accumulation of *details* that are from the "right" time period, or have believable patina of age also contributes to the suspension of disbelief. *Forced perspective* is used to make the space to seem expanded far beyond the physical boundaries of the scene. The objects that are farther away are rendered much smaller to increase the sensation of vast distances. The *change in scale* can alter the perception, so oversized props will make the visitors to have the feeling they shrink down. Many churches are a good example of how to create a dramatic effect with context: "a small hall before the main hall adds impact on the entrance to the monumental interior of the church" (Lankoski and Heliö, 2002).

In the design of spatial attractors, the usage of the *symbols* or *archetypes* is effective. Archetypes are "recurring symbols or motifs". Carson (2000) notes that archetypes are "powerful tools that can be used to draw your audience to experience certain 'feelings' about the space you have designed". Thus archetypes may direct action, and provide atmosphere for action in an interactive scenario.

Lukas (2012) presents a list of *moods* associated with design ideas. He also warns that each of the moods can have potentially positive and negative impacts on the experience in a space. For example, *adventurous mood* is created with design elements that allow for search or journey, like corridors that lead to new spaces. This type of space design can make the participant feel motivated to search, but it can also result in being too focused on the quest in the space, without noticing other elements of the story. A *mood of surprise* can be created by including interactive or unexpected design forms, e.g. triggering sound or special effects. This may create a sense of wonder, but also can raise expectations so the participant expects surprises in every corner.

3.4.2 Spatial Design and Interactivity

Physically interactive storyworlds may use the spatial design to create atmosphere and to guide action. Space and architecture communicates information about the interactive storyworld, thus sets the participant's expectations. The spatial setting reminds the participants of where they are and what they can do. The focus of the participant can be guided by light, placement of objects and structure of the space. Lankoski and Heliö (2002) look at the approaches for computer game design, and point out that space and architecture can be used for communicating the genre, and for guiding the players towards a potential for action. The design should enhance the experience with creating atmosphere, setting expectation and in conjunction with the rules of the game to guide action. The rules of a game together with the spatial design can be used to define which areas are accessible and also in what kind of conditions one must meet to access it.

In film and theater productions the directors choose which part of the scenery will be shown, whereas in a physically interactive environment the participants have a lot of freedom to move in the physical space. For physically interactive environments it is more challenging to achieve believability in scenery design since the scene can be viewed from many different angles. For example, the participants can approach the objects and potentially notice each imperfection in the design.

3.5 Actions and Events

Action is something that is done, while *event* is something that happens at a given place and time. Action is important feature of interactive storytelling: rather than being narrated to, the participant herself has to perform actions to move the narrative forward. In interactive systems, actions by the characters and the participant should also be connected within a narrative plot. Chatman and Attebery (1993) state: "the crucial ingredient of *plot* is not only a series of events, but events so connected that they lead from a beginning to an end, from an initial state of affairs to a concluding one. The connection between the consequent events may be "tight" or loose, e.g. in a detective story the events are very connected, or it can be so loose as to constitute a deliberately chaotic state of affairs. Anyhow, events that tell a story must be connected."

While reading a novel, readers gather knowledge of characters and situations, and may conclude about what may happen next, what should happen next, and what is likely to happen next. Being curious is common for users in traditional storytelling media, but also in interactive media. Roth et al. (2009) analyses curiosity in interactive media and concludes that curiosity in users may refer to the progress of the story, but also to the *action possibilities* that users can try out, i.e. "What will happen if I do this?" It is important that the participants are motivated to act in parts of the interactive space that resolve with interesting development of the story. With their involvement the interactive story becomes more interesting and engaging. If there is a vague range of possibilities, the participant may end up wondering what to do next. The interactive environment may also attract the attention of the participants and guide them, with the help from its characters and spaces.

The recognition of the user's actions in an interactive physical space is done through the integration of signals that are received from the environment. In the physical world the user can act and trigger very complex events. The user can walk or dance in the environment, but if the system does not recognize the action "dance", that event does not exist for the computational system or it may be misinterpreted. Events must be reduced to computational expressions. The input information is usually taken from the context of the story, such as user's location, changes in nearby objects or passed time. Depending on the actions of the user, the system should determine a sequence of unfolding events responding on each action. The actions and events in an interactive system are connected within a narrative plot. In the following, we look at approaches that give high level structure of a plot in an interactive narrative.

3.6 Time

Time plays a central role in many aspects of narration both at the story and at the discourse level. Time determines *pace*, *dramatic tension* and the aesthetic of staging and story development. Genette (1971) established and elaborated the principal categories of *time* in a narrative: order, duration and frequency; described as follows:

- *order* describes the relation between the events of the story and the sequence in which they are related;
- *duration* contrasts the time an event takes to occur in the story with the time it takes for it to be narrated; and
- *frequency* is the number of times an event occurs in a story.

Chatman and Attebery (1993) distinguish between a *story-time* ("internal" time that takes the fictional events to occur) and a *discourse-time* (the time it takes for the narrator to tell or show a story). Following this notation, narrative *order* refers to "the parallelism, or lack of parallelism, between the sequence of the events in the discourse and the sequencing of those events by the discourse" (Chatman and Attebery, 1993). *Discourse-order* parallels *story-order* when the narrator tells the events in the same order as they occurred. In nonparallel or "inverted narrative order", the discourse presents the story-events out of sequence. Chatman and Attebery (1993) summarize four different ways in which *story-duration* may relate to *discourse-duration*: 1) the two durations may be roughly equal; 2) the discourse time may be much shorter than the story-time 3) a period of story-time may be skipped by the discourse entirely 4) the story-time stops for a moment but the discourse-time continues.

Allen (1983) introduces the thirteen basic relations that can exist between temporal intervals. The relations *before, meet, overlap, during, start, finish* can be inverse for the two intervals, except *equal*.

Pinhanez et al. (1997) describes a design paradigm for story-based interactive system, that uses these temporal relations to handle complex patterns of interaction evolving through time. The interaction of a system is described by temporal intervals connected to sensors and actuators. *Timer* is a special case of an actuator that can constrain the duration of an action or sensing activity. Many interactive storytelling engines take in consideration that an interactive narrative should have temporal continuity (Benford and Giannachi, 2008, Riedl and Young, 2006, Swartjes and Theune, 2006, Porteous et al., 2011a,b, Charles et al., 2011). The temporal relationships between the actions in the story plot need to be annotated in an interactive narrative.

In traditional narratives there is only one path of the story presented to the audience, and it is the same path that is taken every time an audience experiences the narrative. An interactive narrative has more than one way to traverse the narrative space and the temporal order. The underlying spatial and temporal structure of the interactive narrative shapes the user experience. There is not one solution regarding narrative structure. Further, we look at the most prominent approaches in interactive storytelling.

3.7 Narrative Structure and Approaches in Interactive Storytelling

There is not one solution regarding narrative structure. The authors determine the decisions about a structure. The authors of an interactive storyworld impose their own goal for the created experience: the user can explore freely in the interactive environment so the structure will be designed for maximum openness or it will have a restrictive structure that nudges the user down a linear narrative passageway. The existing approaches to interactive narrative range from *strong story* to *strong autonomy* (Mateas and Stern, 2002):

- One approach is to structure the drama in scenes or macro-elements, where the order of these elements can be pre-written by the author, or established through a graph or dynamically calculated according to rules. The *strong story* approaches can offer the user a well-formed experience which is unified, efficient and well paced. The parts of the experience contribute to a unified whole and the tension of the experience may even follow a dramatic arc. In this approach the author can keep a global view of the narrative, while allowing the user to interact. The weakness is in the limited interactivity and character-level considerations, such as maintaining character consistency.

- The *strong autonomy* approaches are better able to present the characters. The character-based approaches consist of building rich characters and allowing them to evolve in the narrative world. The user has a high degree of agency and freedom of expression and a space of possibilities that is larger than what is possible in a complex narrative graph structure. However, this approach can not capture narrativity effects such as suspense or conflict, which need a more global view on narrative. Weaknesses are found in authorial control, the control over the course of events, timing and pacing of these events to achieve envisioned user experience.

Interactivity in a narrative is implemented by strategies like *branching narrative* (Gordon et al., 2004, Freeman, 1998), which defines points in the story, at which a user action or decision alters the way a narrative unfolds or ends. *Branching narratives* are represented as directed graphs in which each node represents a linear, scripted scene followed by a decision point. Arcs between nodes represent decisions the user can make. Galyean (1995) numbers several approaches in creating non-linear experiences: branching structure, *maze* and the *river* analogy. The *maze* would have only one path that leads to successful completion of the experience. Galyean also proposed a *river analogy* model for interactive experiences, where the user is compared to a water-skier who is unable to determine the direction of the pulling boat (the story) but who has some freedom to explore his or her current situation in the story.

In video games there is a relatively standardized approach to structure. Usually, the larger division is the *level* and the player works through the levels in a sequential order. The challenges become more difficult as one ascends through the levels, and the ultimate challenges are awaiting the player in the final level. Miller (2004) classifies different interactive models as structures that range from *"angular"* which tend to channel users along a particular narrative path, to *"rounded"* structures that do not support much of a story thread, but they do promote freedom and exploration. Some structures combine "angular" and "rounded" elements and thus can combine narrative within a certain amount of freedom.

Crawford (2012) criticizes some of the approaches of building interactive naratives: the *branching tree* design asks for production of many nodes in the tree, while players experience only part of them; or *environmental approaches* aim to create a large storyworld that provides more resources. Crawford concludes that these approaches do not solve the problem of interactive storytelling, since they only create a rich scenery without dramatic development. Crawford proposes usage of *"metaplot"* to resolve the conflict between plot and interactivity, where the plot is replaced with a web of possibilities and the choice between actions allows interactivity. Crawford (2012) considers a *personality model* to define characters in an interactive story; it would implement the variables: *intrinsic* (integrity, virtue, power, intelligence, attractiveness), *mood* (anger/fear, joy/sadness, arousal/disgust), *volatility* (adrenaline, manic, depressive, sensuality), *accordance* and *relationship* variables (that refer to the relationships with other agents and characters).

Mateas and Stern (2005) introduce narrative sequencing in a form of *beats* (smallest unit of dramatic action), *global mix-ins* (narrative sequencer that can intermix within beats) and *drama manager* or *beat sequencer* (high-level plot decisions are made and causal dependence between major events is handled).

Riedl and Stern (2006) accept the paradigm of high-level directives and low-level agent autonomy, which opens up the possibility of an agent selecting joint behaviors. Thue et al. (2007) present a set of decisions available during storytelling: *selection* concerning the sequence of events that make up the story; *specification* by deciding details concerning the time and place of each event; and at the highest level is *refinement* where the behaviours for each character must be determined.

Character-oriented approaches to narratives, found relative guides in role- playing games (RPGs) and improvisational drama Louchart and Aylett (2004). Aylett (1999) proposes the concept of *emergent narrative* as a possible solution for the clash between the pre-scripted character of a narrative and the freedom afforded by an interactive virtual reality. Aylett states that narratives may emerge directly from the interactions of its characters, rather than having a predetermined plot that guides the experience. This approach takes *improvisation* as basis, the authoring is limited to the creation of characters and their milieu. There would be no pre-determined end to the story or event time line and the development of the story depends on the participant and the intelligent agents. Theune et al. (2003) build on the emergent narrative approach, by introducing agents that are not only self-interested, goal-directed characters, but also drama-directed, collaborative actors.

All of the above mentioned interactive storytelling research project use virtual reality as a medium. The presented approaches are long-term inquiry for creating richer and more compelling interactive narratives. On the other hand, there are not many mixed reality storytelling environments, yet; we refereed to several projects of interactive storytelling in mixed reality in Section 2.5. Several physically interactive stories, presented by Pinhanez et al. (2000) show that in physically interactive stories responsiveness is likely to be more important than choice; such physically engaging experiences feel highly interactive without providing to the participants any real control over the story.

We are taking the *strong story* approach to support the creation of interactive storyworlds in mixed reality. A strong story approach gives more control on the side of the designer. The choice of narrative structure in mixed reality may imply creating of a physical space for the organizational building blocks. Narrative structures as *branching tree* or *maze* may be implemented in way that the user is physically choosing her path in the immersive environment. As Crawford (2012) argued; these types of design asks for production of many nodes in a tree, while participants experience only part of them. However, the decisions about the narrative structure are made by the design team in a specific project.

In this chapter we looked into the established narrative theories, that help us define the story elements that constitute an interactive narrative. We examined the role of characters and settings in creating an engaging storytelling environment. We point out the opportunities from technological and design perspective, by numbering the design methods, elements and principles, and also the challenges, in designing interactive stories as an entertainment medium. Finally, we reviewed the approaches in narrative structure that are used in interactive storytelling in virtual and mixed reality.

4

Technologies and Modalities for Mixed Reality Installations

Mixed reality gives many creative opportunities for designing immersive and interactive narratives. Mixed reality environments posses all the components of other engaging forms of digital entertainment (sound, video, computer generated characters), while also offering storytellers with additional tools to use. These include physical props and sets, robotic characters, new types of spaces and multisensory stimuli. Environments result from the interplay between the real world and the virtual world, that can mutually reflect, influence, and merge into one another.

In this chapter, we review the technological state of the art that allows the merging of real and virtual worlds. First we give an overview of the *sensing mechanisms* that may be used in a physically interactive environment. Moreover, we look into the established approaches in implementing *context-aware systems*. We describe the *actuation technologies* and *modalities* that can convey a story in a physical space: physical actuation, robotic characters, the tools for virtual and mixed reality, lighting, sound and other types of special effects such as olfactory and haptic.

4.1 Sensing

We aim to bring computation into the physical world. The interactive environment must be aware of the users it is interacting with. Such environment may involve unencumbered interaction with non computational objects, that does not require people to attach high-tech gadgetry to their bodies. Interactive storytelling environments rely on rich multimodal sensory data to provide awareness of what is happening in the environment. A design of such a physical space may take advantage of numerous computer vision, speech, gesture recognition systems and growing range of sophisticated sensing technologies. Additionally, techniques for processing and analyzing the captured sensory streams are used to provide the interpretation of the data.

4.1.1 Context-aware Environments: Story as Context

Advances in the fields of distributed computing, mixed reality and pervasive computing have facilitated the development of many context-aware environments in a broad range of applications like homes, offices, factories and location based entertainment. To build compelling and automated mixed reality storyworlds, we have to understand the issue of *context-awareness* in a storytelling environment.

Schilit et al. (1994) describe systems that examine and react to an individual's changing context, and adapt according to the location of use, the collection of nearby people, hosts, and accessible devices, as well as to changes to such things over time. Schilit et al. also state that the three important aspects of context are: *"where you are, who you are with, and what resources are nearby"*. Dey (2001) argues that we cannot enumerate which aspects of all situations are important, as this will change from situation to situation; context is defined as "any information that can be used to characterize the situation of an entity. An *entity* is a person, place, or object that is considered relevant to the interaction between the user and the application, including the user and the application themselves." Zimmermann et al. (2007) defines five categories that describe the elements for context information: *individuality*, *activity*, *location*, *time*, and *relations*.

Context in the scope of *emergent narratives* is defined as "information relevant to a narrative, specifically the user, author, agents, and setting and all subsequent actions or relations of these entities" (Truesdale et al., 2013). The drives and desires of the characters and agents are constructed within the narrative setting, whilst effectively reflecting the interactor's interactions and relationships with them.

In interactive storytelling environment, the *story plot* determines all the available actions implemented in characters and agents; it also determines the actions of the user that are of interest for the development of the interactive narrative. The story plot may set the *location* in the physical space and the relative *time*, where and when certain action is expected to happen to affect the narrative plot. In the previous chapter we described the role of story characters and spatial setting from a storytelling and design perspective. In mixed reality environments: *places* are regions of geographical space such as rooms and corridors; *people* can be either individuals or groups, co-located or distributed; *things* are either physical objects or software components and artifacts.

The context information can also have categories and characteristics: identity, location, status (or activity), and time (Dey et al., 2001). *Identity* allows to assign a unique identifier to an entity. *Location* can be described by the position in a space, but it may also include information about orientation and elevation, or spatial relations between entities, such as co-location, proximity, or containment. For example, information about where an object is in the space, but also if is in an upside down position or tilted. *Status* or *activity*, identifies the intrinsic characteristics of the entity that can be sensed, e.g. a place can have a certain amount of light or noise levels. For a person, it refers to physiological factors or the activity the person is involved in. *Time* often is used in conjunction with other pieces of context, as a *timestamp* or as a *time span*, to indicate when this event takes place; sometimes the ordering of events or causality is sufficient.

The approach of implementing a context-aware system depends on special requirements and conditions such as the location of sensors, the amount of possible users, the available resources of the used devices or the facility of a further extension of the system. An important technical step for building an interactive storytelling environment is the integration of the sensing information from the physical space into reasoning mechanisms that are able to provide the context for a narrative scenario.

The acquisition of contextual information can be done in different ways, Indulska and Sutton (2003) classifie sensors in three groups: *physical* (hardware sensors), *virtual* (software applications and services) and *logical sensors* (couple of information sources, combination of physical and virtual sensors, information from databases). In the next section we give overview of physical sensor types.

4.1.2 Sensor Types

In Table 4.1.1 we present a brief overview of commonly used physical sensor types. *Audio* and *video* sensors are used as high-content sensors, these sensors carry a large amount of content that is essential for interpretation of the activities in an environment. Often *cameras* and phased-array *microphones* can be distributed and embedded in a scene allowing for an elaborate coverage of the space. Such microphones will provide a higher-quality audio stream for speech recognition. Other types of sensors are used to augment the environment, include contact sensors to detect which furniture is in use, or touch-sensitive floor that tracks walking people. *Bio-sensors* measure biological data that can be used to provide information about the internal state of the person. The data from additional sensors in the environment can be merged with data from bio-sensors to offer a more complete knowledge about the user's context. Such combination is referred to in the literature as *data fusion*; whereas *information fusion* refers to the combination of data and information from sensors, human reports, databases, etc.

The final goal of using sensing mechanisms in mixed reality applications is to understand what is happening in the physical world. To achieve contextual knowledge of the space that is being sensed and to model the environment and the people within, methods for both low-level and high-level processing and interpretation are required. Signal processing methods are build to process the sensory data captured from the sensors and to model and recognize the space and the activities in it.

The activities of the participant can be detected by recognition of *identity*, *location*, *expression/gesture*, *audio processing*, *pose tracking*, etc. (Essa, 2000). For instance, the location of the participant is detected with using visual and tactile tracking; *hand gesticulation* or *facial expres-*

Table 4.1.1: Commonly used sensor types

Sensor type	Type of information
Light Sensors	Light intensity, density, reflection, color temperature, and type of light.
Camera	Visual information
Audio	Audio information
Accelerometers	Inclination, motion, or acceleration of an object
Location	Position, location, collocation, and proximity of users, objects
Touch	Detect touch by implementing skin conductance, conductive planes or light sensors
Temperature	Information about temperature
Air Pressure	Altitude or changes in pressure
Passive IR Sensors	Motion or presence
Magnetic Field	Direction of a device or movement
Bio-sensors	Skin resistance, blood pressure, heart-rate
Specialized Sensors	Mechanical, and chemical sensors added together to augment the sensory capabilities

sion can also give information about the activities of the participant and to be interpreted in the context of the interactive narrative scenario. The actions performed by the participants in a physical space may be various and ambiguous, since the participant can take different positions in the environment or different juxtapositions of the physical objects. Context-aware systems can be implemented in many ways, in the following section we give an overview of several approaches and frameworks for context-aware systems.

4.1.3 Approaches in Context-aware Systems

Context sensing is very often distributed over many hardware and software components, which leads to complex distributed designs. The *acquiring of contextual information* can be done in different ways, such as *direct sensor access*, when information is gathered directly from the sensors; *middleware infrastructure* which uses a layered architecture that will hide the low-level sensing details, or with a *context server* that gathers sensor data to facilitate concurrent multiple access (Chen et al., 2003).

Winograd (2001) refers to *models for context management* that are used for coordinating multiple processes and components. Dey et al. (2001) proposed a *widget model* which implements a software component that provides a public interface for hardware sensors. Winograd (2001) introduces the *blackboard model* in which a process posts messages to a common shared message board, and can subscribe to receive messages matching a specified pattern that have been posted.

Dey et al. (2001) look at the challenges that arise from software design of context-aware applications and describe a conceptual framework that supports the ability to transform and collect contextual information. Five categories of components are introduced: context widget, interpreters, aggregators, services and discoverers.

- *Context widgets* would hide the specifics of the input devices and manage interaction to provide applications with relevant results of user actions.
- *Interpretation* refers to the process of raising the level of abstraction, interpreters take information from one or more context sources and produces a new piece of context information.
- *Aggregation* refers to collecting multiple pieces of context information that are logically related into a common repository.
- *Services* execute actions on behalf of applications, and *discoverers* are responsible for maintaining a registry of what capabilities exists in the framework.

Meyer and Rakotonirainy (2003) present a survey on the basic components of a context-aware systems, pointing out the research dimensions that need to be addressed: instrumentation, middleware, applications, user experience and privacy.

Instrumentation refers to the hardware consisting of the sensors, actuators, microcontrollers, and their software and wireless networks which let them communicate with each other and higher-level systems.

Middleware is the system that gathers context information, process it and derive meaningful (re)actions from it. A *hardware abstraction* layer decouples the higher level software from the actual sensor hardware, its software and the communication network. Meaningful context information has to be derived from raw data acquired by sensors. A *context management* module process the knowledge from environmental information sensed by sensors.

Applications are using the gathered contextual knowledge; i.e. the interactive story scenario provides context for the detection of the user's actions and the actuations in the environment.

User experience is everything that the user feels, observes, perceives through the interaction. The system should meet the expectation of the user, to be as enjoyable as possible, and ensure minimal frustration. *Privacy* of the user also has to be taken into account.

In Figure 4.1.1 we depict the needed components in the context of interactive storytelling, based on the one previously described from Meyer and Rakotonirainy (2003). The sensing and

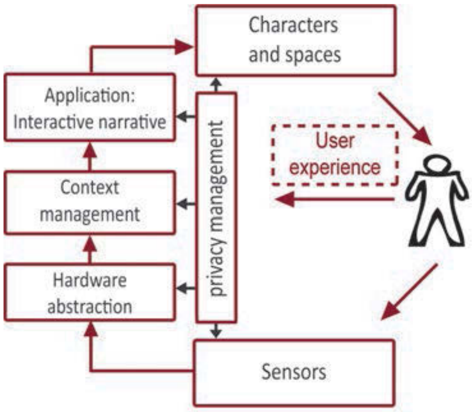


Figure 4.1.1: Basic components of a context-aware system interacting with a user (Meyer and Rakotonirainy, 2003)

actuation mechanisms of the interactive storytelling environment are an instrumentation that acquires context information and executes the narrative scenario. The interactive narrative scenario (application) provides context according to the plot of the narrative. The characters and the spatially and temporally related modalities of the system are interacting with the participant. Further, we will describe the different modalities and technologies that allow materialization of a physically interactive storytelling environment.

4.1.4 COMMUNICATION ARCHITECTURE

Multiple structures have been developed to realize the exchange of data between software components, including message passing, remote procedure calls, shared data, channels and sockets. Tanenbaum and Van Steen (2007) provide an extensive overview and practical implementations applicable in various types of distributed systems. In theory, all of the above structures are equally powerful, because every of these models can be implemented with the concepts of the others. Three widely-used models for communication are: Remote-Procedure Call (RPC), Message-Oriented Middleware (MOM) and data streaming.

Message-oriented middleware (MOM) software or hardware infrastructure supporting sending and receiving messages between distributed systems. It allows application modules to be distributed over heterogeneous platforms and reduces the complexity of developing applications that span over multiple operating systems and network protocols. There exist many general-purpose middleware systems, using many different data exchange and propagation mechanisms, from publish/subscribe to service-oriented and event-based architectures. Middleware environments, as Common Object Request Broker Architecture (CORBA) (Mowbray and Zahavi, 1995), Distributed Component Object Model (DCOM) (Horstmann and Kirtland, 1997) are built on synchronous semantics. Special middleware for context aware applications are Aura (Sousa and Garlan, 2002), Gaia (Román et al., 2002) and others like Mundocore (Aitenbichler et al., 2007), Reconfigurable context-sensitive middleware (RCSM) (Yau et al., 2002) and Security Management Middleware in Ubiquitous computing environment (SMMU) (Jiang et al., 2005). A great number of protocols, technologies and approaches have been proposed, such as Simple Object Access protocol (SOAP) (Box et al., 2000), Universal Plug and Play (UPnP) (Song et al., 2005) web services or high-performance asynchronous messaging libraries as ZeroMQ (Hintjens, 2013).

4.2 Physical Actuation, Robotic Characters and Special Effects

In a mixed reality environment, the physical world must be controlled along with the virtual. A physical storyworld often involves design of actuation elements, vehicles, doors or robotic agents. These techniques are widely used in amusement and theme parks. Amusement parks usually use rides that manipulate the physical state of the visitors: "people are strapped into a mechanical device that carries them up hills, drops them, and then wraps them around numerous twists and turns" (Lukas, 2008).

4.2.1 Rides

Rides are one of the primary means to manage the population within a theme park. Lukas (2008) refers to roller-coaster rides: "in an amusement park it is a thing of sensory and kinetic delight, it throws people together and reminds them of their mortality, while in the theme park it is often a part of the story being told through themming, something that affects body but also the mind." The experience and the time are controlled to precision. The participants are moved along to participate in a unfolding story. Rides ask for unerring precision of the speed and the synchronization of everything else to them, like 3-D films and sounds. Rides might be considered as self-contained themed world and narrative delivery device.

In interactive storytelling environment, often rides and physical actuation are used to enable progress through a story which spans over several physical spaces. The progress through the story often is a journey through a sequence of physical spaces. The pacing in time and order often has to be controlled with literal opening/closing of *doors, gates, curtains*. In an interactive space where the user has freedom to move around and to take actions, the design of the space may aim to distract or to give direction, but it also may literally allow or forbid progress in the story.

4.2.2 Robotic Characters

The *characters* from the storyworld can be *embodied* in robotic agents that can have pre-programmed or autonomous behavior. Ziemke (2001) identifies notions of what kind of body/embodiment is required for (embodied) cognition: *structural coupling* between agent and environment, *historical embodiment* as the result of a history of structural coupling, *physical embodiment*, *'organismoid' embodiment*, i.e. organism-like bodily form (e.g., humanoid robots), and *organismic embodiment* of autopoietic, living systems. The physical embodiment refers to embodied systems that are connected to their environment not just through physical forces, but also through sensors and motors (Brooks, 1990). The physical embodiment of characters in interactive storytelling environments gives many creative possibilities, but also imposes challenges regarding the building of their physical shape and how to enable them for action in the physical world.

The most sophisticated animatronics are designed in theme parks. Disney parks use the so called 'audio-animatronics' to produce the characters and assets for a specific story world (Imagineers, 1996). Imagineers, through the *"Living Character Initiative"*, tackled the challenges of designing "live, interactive characters in both physical and virtual worlds and to interact with guests in new and more personalized ways." These life-like believable characters present the two-dimensional animation of the cartoon into a three-dimensional replicas of people and animals with both sound and movement. A tangle of hydraulic and pneumatic valves are packed inside the character. Wax (2008) presents the sophisticated characters, some of them are free walking characters that have means to interact with the guests in the park. The visitors in theme parks can come close to these characters. Usually these characters are built realistic to the touch, with friendly facial expression that will encourage interaction with guests.

Entertainment robotics (Graf and Barth, 2002) also find application in interactive storytelling as increasingly sophisticated and life-like autonomous robotic technologies mature. There is on-going research in entertainment robotics used in interactive theaters (Breazeal et al., 2003) and live performances (Werger, 1998, Bruce et al., 2000). The key technologies for applying mobile robots successfully in public environments, are navigation and communication skills, and safety concepts.

4.2.3 Special Effects

Special effects are used together with the audio, scenery, and lighting to manipulate physical reality. Special effects support the story with technical solutions, such as combinations of fire, smoke, steam and water, mechanics and optics. The user is hit by blasts of air, sprays of water, unique smells or heat sensations. Special effects create a tactile and visceral impact that can expand the user's scope of perception beyond the limits of visually based experience. Stapleton et al. (2002b) concludes: "when all our senses validate a virtual event, the experience moves us across a credibility threshold." Theme parks rely on different special effects to create the intended mood or events in a storyworld. The designers have to add effects that fit the story plot (Imagineers, 1996).

The design of special effects incorporates electronics, chemistry, lighting or mechanical systems. Alcorn (2010) numbers the technology that can be used: mechanics, electronics, high voltage, pneumatics (air), hydraulics, projection, lighting, and cryogenics. For example, fog can be created with different techniques and materials, water-based or from liquid nitrogen. Projection can be used with moving wheel to create an impression of continuous motion. The special effects require usage of local control boxes, with a local interface that allows maintenance. The materials involved into production of each type of special effects need to be safety proven.

4.2.4 Safety

Safety is an important issue to be considered when interaction is happening in a such physical space. Physical actuation can cause accidents, such as a person being hit by the robot or in during opening/closing of a physical gate. If a physical object is stationary then the responsibility lies partly by the user. These issues ask for safety measures, as for example keeping a certain distance to the robot. Robots usually implement laser scanner based collision detection, so whenever an obstacle is detected in the robot's vicinity, the speed of the vehicle is reduced at a degree depending on the distance to the obstacle. Other techniques are equipment with a rubber bumper all around the vehicle or magnetic sensors (Graf and Barth, 2002). Other possibilities to achieve safety are redundancy (usage of more than one controlling point), emergency stop, control signals, and video surveillance systems. Ride control techniques have to go through severe checks and to implement techniques (such as break beams, failure modes) that will guarantee safety.

4.3 Video, Virtual Reality and Mixed Reality

Apart from physical embodied characters, storytelling in a physical space can also involve video, virtual reality and mixed reality. Interactive storytelling environment can benefit in many ways from these technologies: through creation of story characters, spaces and unique types of interaction.

Parts from the interactive story may be presented in a form of *video*. A video can be a recorded performance in a form of visual images and sound. In the immersive environment, it can be triggered based on the behavior of the user, or to be a part of the sequence of the story plot. Recorded *video* captures visuals from the real world, while *virtual reality* uses computer graphics. For the production of virtual reality environments, crucial technology is the synthesized graphics and sounds, but also the various formats of displays: head-mounted displays (HMDs), CAVE-like (Cave Automatic Virtual Environment) surround projectors, panoramic projectors, workbench projectors, and desktop displays (Brooks Jr, 1999).

Mixed reality allows the digital world to be extended into the user's physical world. Mixed reality can be used to create an almost magical environment where the virtual world animations and graphics are merged with the real world as seamlessly as possible. Lifton (2007) introduces the notion of *dual reality* as environment that results from the interplay between the real world and the virtual world, mediated by networks of sensors and actuators. Milgram and Kishino (1994) discusses three important properties of the various mixed reality systems: reality, immersion and directness.

- *Reality* refers to the characteristics of the environments, some are primarily virtual, in the sense that they have been created artificially, by computer, while others are primarily real.

- *Immersion* concerns virtual and real environments, each can be displayed without the need for the observer to be completely immersed within them.

- *Directness* addresses whether primary world objects are viewed directly or by means of some electronic synthesis process.

There are also many examples when mixed reality is applied in education (Liu et al., 2007), and entertainment (Stapleton et al., 2003, Tamura et al., 2001, Magerkurth et al., 2005). Cheok et al. (2009) present several systems which are combinations of art, culture, entertainment, and technology providing mixed reality interactions in MediaMe, BlogWall, and Shared Design Space. Hughes et al. (2005) presents diverse applications of mixed reality technology for military training, education and entertainment; such examples are Military Operations in Urban Terrain, and MR Sea Creatures implemented in Orlando Science Center.

4.4 Lighting Design

Lighting design is an important element to visually compose a setting. Stage lighting and the design of the space are important parts of a storytelling environment. By using *fixed lights*, the lighting designers can design illuminated space and can give accent to specific parts of the scenes or characters. By using *color*, *direction*, *texture*, and *intensity*, lighting can add another dimension to the environment, as well as to provide cues to mood changes in the story plot. A dark interior allows lighting to focus the visitor's attention on the elements that are most important to the story.

Designers use lighting not only for *visibility*, but also for *emphasizing* visual tension, directing users gaze and action to important objects/characters/areas, and providing *mood*. In a storytelling environment, lighting is used to create dramatic effect to increase the realism and to reveal different physical elements as the story unfolds.

Lighting designers need to select the appropriate lighting design, but also have to select and locate fixtures, colored filters, control equipment (Fraser, 2011, Shelley, 2013). The types of light sources that can be used in different settings have various qualities and features, as described in Ganslandt and Hofmann (1992). Light is controlled using various optical phenomena: reflection, transmission, absorption, refraction, and interference (Karlen et al., 2012, Ganslandt and Hofmann, 1992). Dimming control technology and electronic dimming ballasts can be used to control light levels and are particularly useful for reducing light levels. In interactive environments the lighting designers should be able to add, remove, and change the position of a light in real-time. It should also be possible to modify the light's *attributes* such as beam width or fall-off position.

4.5 Sound

A well-designed soundscape may blur the border between the real and the fictive and helps to enhance the sense of immersiveness in a storytelling environment. Users immersed in such a storyworld will become more emotionally and viscerally involved in the story and less aware of the outside environment. An effective and well designed soundscape can have a strong impact on the perception of an environment and the feelings of immersion and dramatic involvement.

4.5.1 Sound Types

The film industry has recognized the importance of sound and has developed techniques for producing sound that allows the audience to feel immersed. There are several types of sound used in the entertainment industry. The sound has two basic roles: *story telling* and *story supporting* (Dakic, 2007). *Story telling* is possible with using dialogues, monologues or off-narration, while *story supporting* relates on the sound effects that enhance the tension in film and suggest to the audience how to feel .

Other used division is on sounds that are coming from the storyworld (*diegetic*) and sounds from outside the space of the story events (*non-dietetic*) (Bordwell and Thompson, 1985, Ekman, 2005). *Digetic sound* is any sound presented as originated from sources within the simulated world. The source for a diegetic sound is visible on the screen or is implied to be present by the actions; it is the sounds made by objects in the story, the voices of characters, or music represented as coming from instruments in the story space. *Non-diegetic sound* is coming from the a source outside story space, such as: narrator's commentary, sound effects which is added for the dramatic effect or mood music.

There are many attempts to describe the role of sound in games. Stockburger (2003) provides detailed categorization of game sounds based on the typology of sound objects. Bernstein (1997) defines three sorts of game sound types: *direct*, *indirect* and *environmental*; his classification uses the audio object vocabulary, taking that the objects talk to each other and to the player.

The entertainment industry, as film and theater, uses *speech*, *sound effects* and *music* (Liljedahl, 2011) to convey a story:

Speech (dialogue, monologue, over voice) Speech and dialog conveys clear messages with least possible risk of misunderstanding.

Sound effects (hard or "cut" effects, foley sound effects, ambience, backgrounds, designed sound effects) are the sounds that result from events in the physical world like the ticking of a mechanical clock, closing a door or steps on a cracking floor. Ambient sound creates a sense of physical presence that can set the basic mood and it can communicate emotion and arousal. The sound effects exaggerate reality to create an immersive experience, for example sound with an added slight amount of reverb can create a sense of volume.

Music (recorded music, live music, background music) can be used to set the basic mood or to encourage activity; it can create succession of tension and relief or to create expectations or dreamy mood. Music and sound effects can convey semantics in a very universal way, as the users know very quickly what it means. The users can immediately relate to familiar music, which greatly enhance the experience and creates a sense of presence and immersion. Music induces feelings, communicates subconsciously and makes the visitors feel in a certain way.

Sound designers are using the basic properties of sound: *pitch*, *loudness* or *volume*, *timbre*, and *harmonics*. *Pitch* is characterized by the frequency of a sound wave, whereas the amplitude of a sound wave determines its *loudness* or *volume*. In music, *timbre* or *tone color*, is the quality of a musical sound or tone that distinguishes different types of sound production. *Harmonics* refer to the sounds which are produced at multiples of the same frequency as a base sound (Erickson, 1975, Sonnenschein, 2001).

Gaver (1993) makes a distinction between *everyday* and *musical sounds*, and notes that the sound can be listen in terms of its *attributes* or in terms of the *event* that caused it. Gaver (1993) provides a descriptive framework and mapping distinguished by classes of materials, involving *vibrating solids*, *aerodynamics*, and *liquids*. For instance, the sounds made by vibrating solids may be caused by impacts, scraping, or other interactions. Aerodynamic sounds may be made by discrete, sudden changes of pressure (explosions) or by more continuous introductions of pressure variations (gusts and wind). Liquid sounds may be caused by discrete drips or by more continuous splashing, rippling, or pouring events. The sounds may also involve hybrids of different sources at once. *Sound effects* use recordings of such everyday sounds to simulate certain property in a mediated environment.

4.5.2 Sound for Interaction

There are key differences between sound in film or theater, and interactive environments. The designers of film sound create a soundtrack with a specific duration which corresponds to the length of the visuals. Similarly, rides in theme parks have timed movement that can be appropriately mapped with sound design. In an interactive storyworld the characteristics of the environment vary according to the input of the user. Therefore, a dynamic soundscape is created that responds to the changes caused by the user. We take in consideration the following design issues:

Events and action sounds The mixed reality setting imposes a design challenge of a seamless audio integration that will blur the boundaries between the fictional and physical world. Action sounds are manifesting the user's impact on the story world. It may provide action feedback, the sound provides information about the action, but also and about the environment.

Interruptions and transitions To implement interactivity, the soundscape needs to be interrupted depending on the actions of the user. The transition between samples should happen gradually without breaking the experience. Often used techniques are blending, recomposing, or fading.

Repetition and variety It is necessary to create a soundscape which does not repeat at a rate perceived by the user. Looping and triggered ambience are techniques used in sound design.

Loops can easily be perceived as unrealistic; ways to mask the loops is by collecting a database of sound events and ambience sound, and to play them at random rate.

Exaggeration The exaggerated sound events are likely to increase the sense of immersion and to capture the user's attention.

In this chapter we displayed a wide range of available technologies that can be used in a mixed reality environment to provide interactive storytelling experience. We referred to the state of the art technology and approaches. The modalities of the immersive storyworld include physical actuation, virtual and mixed reality, sound, lighting and special effects. Besides introducing all these modalities, we presented some of the basic design elements and properties of each of them. This palette of technologies is very broad and can never be fully complete. The overview provided in this chapter would can serve as a guide to the future designers of immersive storyworlds.

Part II

Design

5
Redesign of the ALICE Installation

In order to examine the critical questions of what constitutes the user's experience and which are the basic factors important for designing interactive storytelling environment, a range of practical explorations were conducted in the immersive and interactive installation ALICE. In this chapter we will give an overview of the redesigned ALICE II installation and the technical and interaction possibilities that were practically explored. We will present our motivation and the redesign of each stage, the reflections on the achieved improvements and the disadvantages of the implemented design solution.

The design iterations in the ALICE project gave us the opportunity to practically explore the technologies and modalities that contribute to the user experience in an immersive mixed reality installation. The technologies presented in Chapter 4 were used for the design of parts of the installation, and we reflected on how they enrich the user experience.

Apart from the research goals regarding the user experience in the mixed reality environment and its technological objectives, we were interested in observing the *design and development process*. This allows us to derive conclusions about potential improvements in the design process and suggestions on how to support it with better design tools.

5.1 The Second ALICE Installation

The six stages from the ALICE installation were rebuilt on a new location (inside Corona building at Eindhoven University of Technology), in the period from June 2009 to July 2010. A new

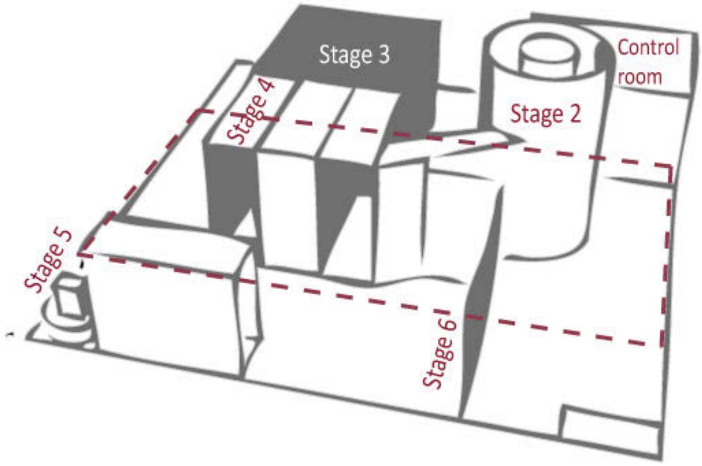


Figure 5.0.1: Schematic drawing of the lower floor of the installation

wooden construction was designed for the installation, the physical space was reconstructed to suit the existing prototypes and concepts from the first installation. Constraints and spatial requirements were taken into account, like required height/distance for projectors. A specialized control room was build to situate all the needed equipment.

Figure 5.0.1 shows a schematic drawing of the lower floor of the installation. Stage 1, indicated with dashed lines, is on the upper floor and it is depicted separately on Figure 5.2.1. Figure 5.1.1 depicts part of the installation and part of the design team.

Figure 5.1.1: Part of the ALICE II installation and part of the design team building prototypes and working in the control room

Taking the novel "Alice's adventures in Wonderland" as an inspiration, many possibilities arise for the implementation of the interactive narrative. In the previous chapters of Part 1 we presented different theoretical views of what constitutes a narrative. We followed the structuralist theory to describe the story elements, which argues that each narrative has two parts: a *story*, the content or chain of events (actions, happenings), and existents (characters, items of setting); and *discourse*, that is, the expression, the means by which the content is communicated. The presented

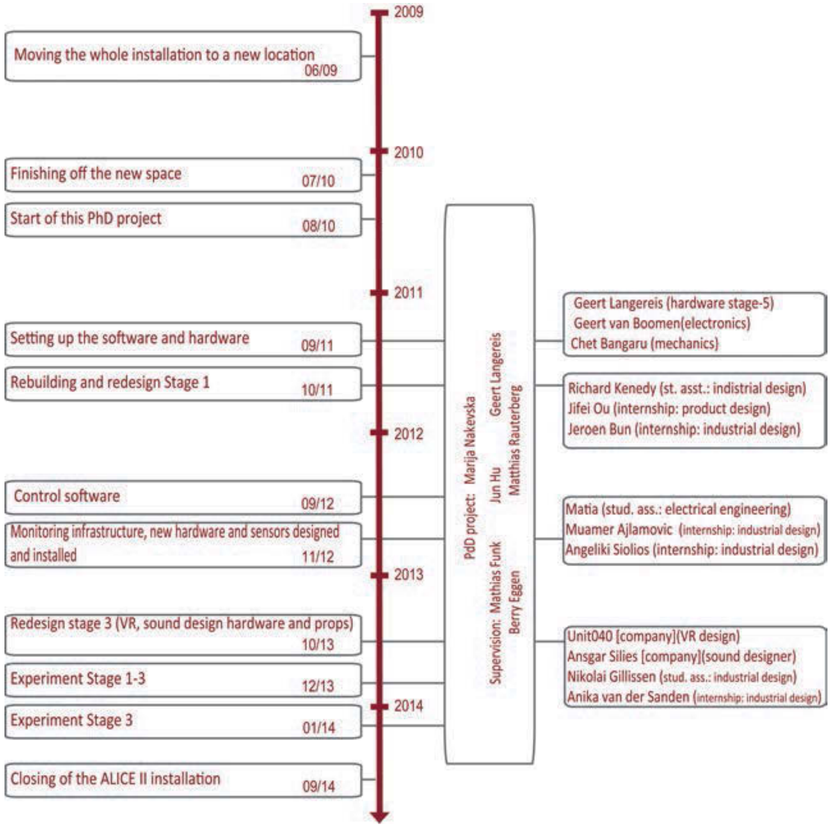


Figure 5.1.2: A timeline of this PhD project in relation to ALICE project, important events (left) and involved researchers, experts, technicians and designers (right).

story plot determines the possible *actions*: walk, “fall down”, eat, drink, talk, take, move, etc. The story plot also determines the characters and agents, the physical settings and props that help the story to be conveyed. In the second ALICE installation, we redesigned the first three stages to improve the realized story plot, to overcome the technical challenges and to research the effects of different modalities on immersiveness and interactivity in a storytelling mixed reality environment. Due to the time and resource constraints the other three stages were not fully redesigned.

5.2 Redesign of Stage 1: “In the park”

The design team, consisting of project managers and industrial designers, reviewed the objectives that need to be achieved in *Stage 1* and the difficulties in achieving them. The installation aims to induce a similar experience as Alice had in the book. The goal of Stage 1 is to make the user *bored* and then to trigger her *curiosity* so she will follow the White Rabbit into the next stage. The physical space for Stage 1 needs to create a feeling of being in a park environment.

We reflected on the knowledge gathered through empirical research in the first ALICE installation (Aart et al., 2010) and the practical issues in achieving the intended story scenario. Aart et al. (2010) addressed the sequential arousal and interdependencies of boredom and curiosity as drives for the behavior of the user. Aart et al. (2010) introduce "design guidelines for arousing *boredom*: 1) induce sensory deprivation by reducing external stimuli to a minimum; 2) create monotony, by using highly predictive repetitive stimuli; 3) prevent drowsiness by using stimuli with high intensity; 4) do not satisfy the need for excitement; rather use the user's expectation to create an anti-climax; 5) avoid any novelties, changes and surprises; everything should seem in place and make sense; 6) do not mention a wait on forehand, nor explain the length and reason of it; 7) emphasize the passage of time during a wait."

Curiosity on the other hand, is triggered by elements that oppose to these 'boredom' guidelines: "use novelties, changes and surprises." Aart et al. also notice that some of the guidelines cannot coexist together, e.g. 'sensory deprivation' and 'prevent drowsiness' are contradictory. 'Sensory deprivation' might lead to boredom but has the risk of resulting in drowsiness instead; 'prevent drowsiness' on the other hand, is likely to prevent drowsiness by applying high intensity stimuli but might not arouse boredom. The proposed modifications from this empirical research (Aart et al., 2010) were: 1) split or block the space with physical objects (curtain, gate); 2) limit the physical exploration and 3) hide parts from the space and objects from the sight of the user.

These empirical and theoretical insights and our practical work on rebuilding of Stage 1, implied redesign of the spatial setting and the embodiment of the White Rabbit. Also, the storytelling system has to implement a specific timeline of the storyplot and to impose drives for the behavior of the user. For each of the story elements of the design, we elaborate on the motivation for redesign, how it was conveyed and which are the advantages and disadvantages in comparison with the design in the first ALICE installation.

5.2.1 Character: White Rabbit

In Section 3.3, we presented the methods for designing characters and the process of characterization with the sub-tools: appearance, dialogue and actions. The *appearance* as well as the *dialogue* of the White Rabbit are inspired by the novel (a white rabbit in bigger size, which has a coat and a pocket watch). The White Rabbit is depicted in many different ways in movies, cartoons, books and video games. The *actions* are also described in the novel: fast running, goes into the "rabbit hole", looks stressed; summary of the narrative is given in Section 2.6.4.

Motivation for redesign. In the first ALICE installation, a *physical rabbit* was designed to guide the user to the "rabbit hole". The abilities and features needed for the described actions, were difficult to be implemented: how to set the *path of the rabbit's movement* (the first prototype was manually operated with remote control), it should be *fast* (the remote controlled prototype was rather slow), the simulated *behavior* (it should jump instead of crawl to the hole). Additional *technical challenges* concern the known issues in designing robotic agents: energy, obstacle

Figure 5.2.1: Redesigned Stage 1

avoidance, design of actuation, etc (Khatib et al., 1999, Latombe, 1996).

Design. To redesign the rabbit, we looked into real life experience: a rabbit usually moves quickly, it is difficult to witness their movement for a long time in a natural environment. In the movie realization *"Alice in Wonderland"* directed by Burton (2010), Alice also does not witness the whole process of the rabbit jumping to the hole: she tracks it by shaking bushes, which indicate that the rabbit just passed by.

Inspired by this, we proposed a concept of chaining projected animation and physical actuation. A cartooned drawing of the White Rabbit was projected on a sequence of screens, in between a *physical artificial grass* performs actuation that imitates movements in the grass. Each of the grass modules implements five motors that spin and with that they imitate movement (Figure 5.2.2 (a))Three projectors are used to project the animation in different places, the animation starts at projector 1 and ends at projector 3 (Figure 5.2.1). The rabbit jumps from screen to screen thereby leads the visitor to the rabbit hole, while the physical grass that places nearby the projection is actuated correspondingly. When the projected rabbit passed across the projections, the grass will vibrate as if a real rabbit passed by.

Reflection. The redesigned character of the White Rabbit (Figure 5.2.2) may be compared with the physical robotic agent from the first ALICE installation (Figure 2.6.3). Empirical research shows that a robotic character has many advantages due to their physical embodiment, in comparison with a virtual character (Fridin and Belokopytov, 2014). A screen character is easier to be developed than a robotic character because a virtual world can be controlled easier, while robotic characters need to deal with uncertain sensory data and a unpredictable environment (Bartneck et al., 2004).

The redesigned rabbit allowed the character to be presented in a more abstract way. The physical actuation, together with the virtual projection were perceived effective, realistic and intriguing. The implementation of a mixed reality character was also technically feasible and robust. The goal of the White Rabbit character is to change the behavior of the participant: from passive to active and explorative. As the rabbit is showed on several places in the setting, it intends to lure the participant into the rabbit hole. Physically embodied agent, with its appearance and movement, would be more persuasive and effective to lead the participants physically to move

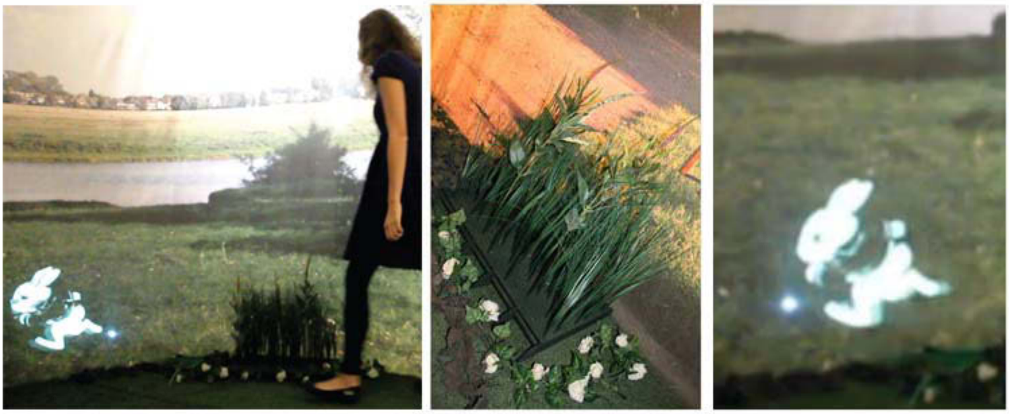


Figure 5.2.2: The redesigned White Rabbit: (a) user "following" the rabbit (b) "moving grass" prototypes; (c) the projected VR rabbit

to the next stage.

5.2.2 Spatial immersion and storyplot

Motivation for redesign. To simulate a park environment, we used the panorama picture from the first ALICE installation which depicts natural environment on a 360 degrees canvas. We took the challenge to enhance the environment with additional design elements that will ensure that the participants will go through the intended story scenario. We want to make them bored for ten minutes, and after they see the White rabbit to become curious to follow it, and to move to the next stage. From the experiments conducted by Aart et al. (2010), it was known that the participants very fast are going to the rabbit hole; the only way to stop them is to physically close the entrance. We wanted to experiment with enriching the spatial setting, sound design and adding sensing and responsive features.

Design. We added more decorations within the room: grass, rabble, artificial flowers, leaves and netting. We covered the "rabbit hole" with more net and artificial grass, as an additional measure to try to keep the participant from entering the "rabbit hole" too early. However, the "rabbit hole" is the only part of the space that will attract the attention of the users. The first pilot test showed that participants would enter the "rabbit hole" in 3-5 minutes. In addition to the visual appearance, *sound* and *music* are strong conveyors of a mood in a space. We designed a soundscape that consists of nature ambiance and singing birds combined with pleasant piano music.

The actions of the participant can be detected by the environment, and can be directed with the stimuli coming from the environment. We wanted to detect when the participant approaches the "rabbit hole" and then to divert her attention to other direction. We added a pressure sensor to detect when the participant is close to the "rabbit hole". If the participant approaches the "rabbit hole" before the White Rabbit "runs" into the scene, the positive and dreamy mood of the ambient sound will be changed (into ambient sound featuring crows and dramatic piano music; and one of the grass modules (on Figure 5.2.1 labeled with 1) starts moving. The soundscape is changed back to the pleasant one, when the participant goes away from the rabbit hole. When the participant is expected to continue in the next stage, the volume is faded out for the ambient sound from *Stage-1*, while a "wind" sound starts from *Stage-2*.

Despite these measures, a pilot test showed that if we want to keep the participants not to enter the "rabbit hole" earlier, we need to close it physically, and open it when we want to allow entrance. We installed a curtain that is attached with electrical magnets and opens when the electricity in the magnets is switched off. The pilot tests also showed that not all of the participants will go further to the "rabbit hole", some will hesitate to explore. To motivate such behavior we need to design more dialogue for the rabbit that will invite them to go further.

Reflection. We did not conduct separate experimental studies about the effects of each enhancement in this Stage. We received feedback from the participants in several pilot test, and we observed the behavior of the participants in the study performed in Stage 1 to Stage 3, presented in Chapter 9.

We may conclude that the enhancement of the environment changes the behavior of the participants. When they trigger the responsive feature near the "rabbit hole", they would react and go back to check the movement of the artificial grass. However, after looking for other possible interactive features they are again bored in a short time, and want to continue further, and with that the intended storyplot is not fully performed. Addition of other interactive features that will draw them away from entering the "rabbit hole" by being entertained in this stage, contradicts our intention to make the participant bored. Therefore, we had to physically stop the participants from going further, until that is allowed by the storyplot.

5.3 Redesign of Stage 2: "Down the rabbit hole"

In the second stage *"Down the rabbit hole"* the user is transported from the safe "park" environment into a different space that is rather peculiar and unusual. The inspiration for the design of this stage comes from the novel (Carroll, 1865) but also from other visualization as cartoons, movies and video games. Salem et al. (2006) proposes the first design guidelines for this stage: "The rabbit-hole goes straight on like a tunnel, and then dips suddenly down, so that the user has no opportunity to stop him- or herself. Either the 'rabbit hole' is very deep, or the fall is very slow, for the user has plenty of time as she slides down to look around and to wonder what is going to happen next."

The physical realization of this type of movement of the user has to to meet many *safety regulations*. A *ride* is a commonly used physical storytelling mechanism in theme and amusement parks; Lukas (2008) refers to ride as "visitors step into a mechanical device that carries them up or down, while the story is told with theming, by using physical props and characters".

Motivation for redesign. The main objectives in this stage is to cause disorientation and

Figure 5.3.1: *Stage-2 "Down the rabbit hole"* (a) *Stage -2*, the "rabbit hole" with bookshelves and lighting (b) The electronic seat and the security gate in the background.

transportation of the participants into 'a new world'. It also has a goal to transport them physically to the lower floor of the installation. Enhancing the disorientation and immersion in the environment, would contribute positively to the goals for the experience in this stage.

The physical ride through the vertical tunnel, except with the lighting design can be enriched with sound design. In Chapter 4, among the palette of technologies and modalities, sound design was presented as a modality that has strong effect on the perception of the environment and the feelings of immersion and dramatic involvement.

Design. In the first ALICE installation the "falling down" action implements a ride: the user is safely transported in a vertical tunnel in a chairlift (Figure 5.3.1). The tunnel has many shelves and lamps that are slowly dimmed on and off. The ride lasted four minutes, and the movement down the tunnel was synchronized with the dimming of the lamps.

We implemented the same physical setting from the first ALICE installation. However, we looked into ways to enhance the experience in the physical space. The feeling of falling down into a deep well was enhanced with adding *mirrors* on the floor, so the participants are disoriented by the reflection of the tunnel and not being able to see the end of it.

A dedicated soundscape for this stage was composed by a sound designer, the soundscape needs to be synchronized with the physical reality to enhance and support the visual and kinetic experience. The implementation of such a soundscape asks for adjusting the timing of the sound effects with the physical movement and the position of the physical elements. For instance, as the ride approaches the dimming lights, sound effects are played to suggest electricity, or when approaching a clock, sounds effect featuring ticking clock is played. The soundscape enhances the mood of the fantasy world with piano music and "mystical" sound effects.

Reflections. Pilot tests showed that the addition of the mirrors on the floor indeed enhanced the feeling of being disoriented in the physical space and not knowing how deep it is. We believe that the sound design contributed significantly to the immersion in this stage. However, we did not conduct a dedicated empirical study.

5.4 Redesign of Stage 3: "Eat me, Drink me"

The third stage is a 5-sided Cave Automatic Virtual Environment (CAVE) of 3x3x3 meter, made of white semi-translucent canvas. We use back-projection to project a seamless virtual environment onto the walls and ceiling of the CAVE. As the participant enters this stage, a sliding door closes behind her, and becomes trapped in this cube room. To continue further out of this room, the user needs to find the right relation between her size and the room and to "open" the door.

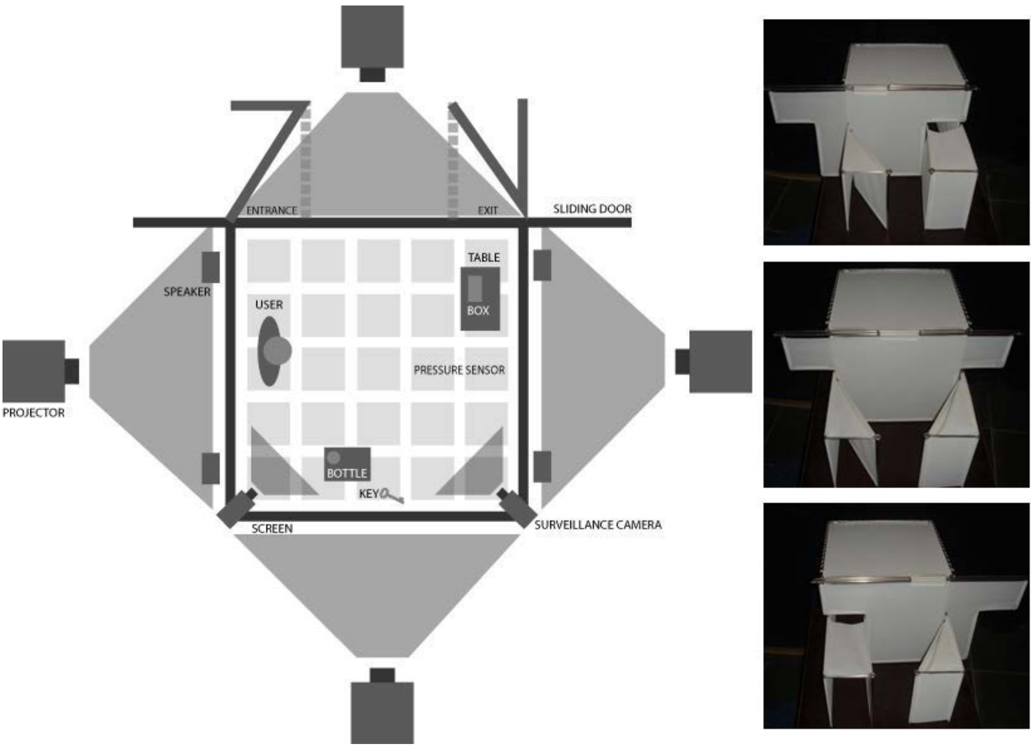


Figure 5.4.1: Schematic overview of the physical setting of *"Eat me, drink me"* stage.

5.4.1 Spatial design

Motivation for redesign. During the reconstruction of *Stage 3*, we reviewed the implementation of the existing CAVE. The redesign addressed the projection mechanisms and the control system for synchronization of the five projections. The projection would benefit from better hardware equipment which will suit the limited space in the installation, also we considered usage of different software for the control of the synchronization of the CAVE.

Design. The physical CAVE installation was reconstructed to use a short throwing distance projectors, which enabled usage of the limited available space, while it maintains life-size projection screens for a better immersion experience. The room enclosing the CAVE installation offered a maximum of 2.2 m of space on each projecting side. Due to this limitation in the physical space available, Hitachi ED-A100 XGA projectors were used. These projectors offer the advantage of short throwing distance and easy image adjustment to cover the square canvas of the projection screen. Furthermore, the back projection nature of these devices allowed us to mount them at 4.0 m above ground outside of the room, enabling free transit around the CAVE without undesired shadows appearing on the canvas. Each projector was then connected to a computer that controlled one of the projected sides of the room. A schematic drawing of the physical space is presented in Figure 5.4.1.

In the first ALICE installation the Vizard VR Toolkit was used to synchronize five projections (four walls and the ceiling). Researchers at the Designed Intelligence group (Juarez et al., 2010) implemented a CAVE system named Cryengine automatic Virtual Environment (CryVE) based on the game engine CryEngine2, which promises for low-cost implementation.

In Nakevska et al. (2011) and Nakevska et al. (2012b) we describe some of our explorations with such a game engine as the driving software for mixed reality installations. The team members engaged in working on this stage, had more expertise in importing 3D models with using the Unity3D game engine. Hence, we implemented the CAVE system in Unity3D game engine by using a client-server connection for multiple screens and pre-programmed positioning of the camera in the virtual space.

Reflections. The spatial setting of this stage consists of virtual reality setting. The change of the hardware allowed us to easily adjust the projection on the screens; while the software allowed us to implement a low-cost CAVE that satisfied the needs for our research.

5.4.2 Interactivity

Motivation for redesign. The implemented interactive story, as it was in the first ALICE installation, lacked feedback from the interactive environment. To enable richer interaction mechanisms, we implemented characters from the story, that give feedback, based on the actions of the user and the development of the story. Since the ALICE installation has six stages in total, the participants has to go through each stage in a limited amount of time. We aimed the interaction design to support each participant to move on to next stage in three to five minutes.

In ALICE I, the interactions for the eating and drinking actions were implemented in a cookie box labelled "Eat Me" and a bottle labelled "Drink Me". These objects contain sensors to register interaction accordingly. We needed to change the obsolete technology implemented for the interactive props "Drink me" and "Eat me" from the first ALICE installation. The previous implementation, of a microphone that would recognize chewing sounds was not successful: first, it was not accurate in the detection; second, we could not have control of the position of the participant, when the person was far from the microphone, no sound can be detected.

Design. Each side of the CAVE shows one projected door (see Fig. 9.3.1 (c)), however, only one VR door is shinny white and smaller than the others, (Fig. 9.3.1(a) and (b)), indicating a potential escape in the real world.

Several completely new interactive features, were designed, in order to increase the participant's engagement in this stage, and to persuade her to act according to the storyplot. The addition of these interactive features was done with incremental iterative design process, more about the design process will be explained in Chapter 7.

Figure 5.4.2: Physical objects in the immersive environment

Eat me, drink me. We implemented a box equipped with an IR sensor that detects movement when the participant takes a cookie, and a bottle that contains a wireless connected tilt sensor which detects if the participant is drinking from the bottle. XBee platform for wireless transmission of signals from the tilt sensor was used, as a smaller piece of hardware that could be implemented in an appropriate object (bottle). When the participant performs an action (eats or drinks) the projected room becomes smaller; giving the participant the impression that she is growing. When she performs a second action (eats or drinks) the room becomes bigger, giving the participant the impression that she is shrinking. Both actions feature an appropriate sound, which emphasises the impression that the participant is getting smaller or bigger.

The key. Behind one of the tables, a physical key with a label "Take me" is hidden; to find the exit from the room, the participant should take the physical key. By using the Wizard of Oz method, it can be indicated to the system when the participant has the key with her. The action of taking the key is coupled with a virtual key that appears in front of the virtual door featuring VR sparkles and a piano "fantasy" sound.

Cracking floor. We cover the floor with a grid of pressure sensors to measure the position of the participant in the room. Each step on a pressure sensor results in a cracking sound played on loudspeakers. The cracking sounds are different depending on the previously taken actions.

If the participant is “big”, the cracking sound of the floor is heavier, and vise versa, the cracking sounds are shorter and lighter.

Ambient sound. An ambient sound is played in the background that consists of fantasy music and dropping water. The “water drop” sound features a different echo depending of the relative size of the VR room.

Figure 5.4.3: The virtual room and characters. (a) User inside the CAVE (b) VR door with interactive doorknob (c) White Rabbit in the Garden

The garden and the White Rabbit. If the participant approaches the door and has the key in her hand, the virtual door will open. If the VR door opens the participant sees the White Rabbit in a beautiful garden waving and saying: *“Oh, dear! Oh, dear! You will be late”*.

A narrator voice. It gives guidance based on the participant’s behavior. As the participant moves around in the environment, the number of triggered pressure sensors is counted. When the number of steps passes eight the narrator voice says: *“Are you just moving around in here, will you ever find the way out?”*. If standing on the same position is detected the narrator voice says: *“Oh dear! You are just standing here!”*. For all of these replies a set of similar speech was recorded and was played one of them in a random way.

The doorknob. The position of the participant in the room is used as input for the interaction. The interactive doorknob gives hints for participant’s actions. When the participant comes closer to the VR door and is too big to fit through, the doorknob says: *“Sorry! You’re way too big.”* When the participant approaches the door and has no key with her, the doorknob says: *“No use. Haha! I forgot to tell you. I’m locked.”* To facilitate the progress through the story, we introduced explicit feed-forward hints from the interactive doorknob, like *“Alright, try the bottle”*, *“Now try the box on the table”*. After three minutes, the doorknob gives the appropriate guidance, depending on the last taken action from the participant and waits for the participant to finish it.

Reflection. We aimed to engage each participant to successfully finish this part of the interactive story. The described interaction features gave sufficient feedback and feedforward mechanisms to ensure meaningful plot for each of the participants. The responsive environment would create different scenario depending on the actions of each participant.

To establish meaningful interaction in interactive storytelling, the users’ actions and the events of the narrative are coupled to generate guiding information. This calls for the design of a set of affordances in which interactive and behavioral aspects of the interactive narrative environment influence the user and evoke certain expected behavior. Feedback and feedforward are one of the most common used design principles in interaction design. Through feedback the user receives information about the effectiveness of her action, whereas feedforward communicates what kind of action is possible and how it can be carried out.

In comparison with the previous design of the “Eat me” prop, we have simplified the technical realization; which does not detect actual eating. We considered a possibility to use Wizard of Oz technique, as we observe if the participant actually eats the cookie. However, that would be too much demanding from the researcher who would act as a wizard. From our observations we noticed that the participants are not having high expectation on the sensing in the physical environment. They are not completely aware how their actions are detected and which action exactly caused the feedback from the environment, e.g. taking the cookie versus eating the cookie; approaching the door or making specific gestures. The empirical study investigating the user experience related to different interaction mechanisms in Stage 3 is presented in Chapter 10.

5.5 Control Structure

The numerous sensing and actuation mechanisms in the described stages lead to *complex distributed system*. In such type of system, the choice of the appropriate interprocess communication and synchronization tools is an important design issue. A communication architecture which allows for connecting of all the heterogeneous distributed components is necessary to facilitate the process of integration of various hardware and software components. Constructing an interactive environment usually involves an iterative design process. Thus, it is important to minimize the effort that is necessary to iteratively implement a certain feature.

In Section 4.1.1 we reviewed several frameworks for implementing distributed context-aware systems. Winograd (1997) describe three context management models: widgets, networked services and blackboard model. *Widget* is a software component that provides a public interface for hardware sensors; they hide the low-level details of sensing and ease application development due to their re-usability. The service based approach, *networked services*, resembles the context server architecture. *Blackboard model* represents a data-centric model, in which processes post messages to a blackboard, and subscribe to it to be notified when some event occurs.

A *blackboard (publish/subscribe)* system allows very flexible decoupled n-to-n communication which is especially useful for prototyping systems. A blackboard system provides a shared memory framework that agents can use to store and exchange knowledge. The components, contributors, communicate by updating the blackboard which is accessible by all the components and serves as central communication point to exchange data between them.

We found the *blackboard model* to be suitable for implementing such automated distributed system, since it gives additional flexibility, provides simplicity in adding new context sources and easy configuration. Further, we describe the implementation of a controller for the interactive

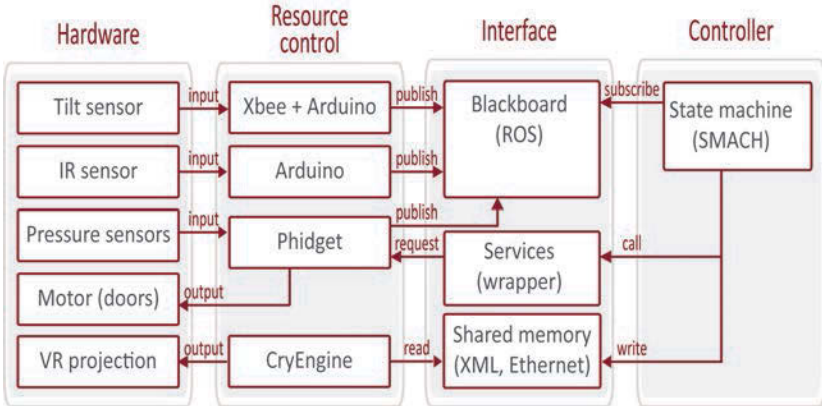


Figure 5.5.1: Iteration 1: An implementation of a blackboard communication interface and a state machine for *Stage 3*

story scenario.

In Section 4.1.4 we gave overview of many communication architectures and approaches. We do not want to create a new middleware on our own, but we are using a middleware which is already existing and working. We found that the middleware ROS - Robot Operating System (see www.ros.org), fits our purposes . Advantages of using ROS are the profit of large community that improves the drivers and the middleware, and the compatibility with large pool of hardware systems. With that it reduces the time for implementation of communication methods.

We integrated the hardware actuators and sensors by employing a unified blackboard interface implemented using the Robot Operating System (ROS) . The controller for the story plot is implemented as state machine in SMACH (Bohren and Cousins, 2010). Each sensor and actuator is interfaced with appropriate microcontroller, using Phidgets (see *www. phidgets.com*) or Arduino microcontrollers (see *www.arduino.cc*). The events are interpreted depending whether they model sensory observation or hardware actuation. In the former case, the event is interpreted as a subscriber function that reads the status of the sensor from the Blackboard interface, whereas in the latter situation, the hardware is actuated by means of wrapper services for the Phidgets that control the door motors, or by employing proprietary interfaces for the game engine that drives the virtual reality component. The state machine for the story scenario uses the available components, the needed sensing mechanisms to complete the scenario, and the coordination requirements that specify the desired interactions that should be fulfilled by the user.

The unifying communications interface basically intercepts communication signals from the sensors, actuators and the props, and it publishes them either as shared memory variables, service wrappers, or to the Blackboard interface of the Robot Operating System, which depends on the technical support available for the components. The interface serves as a communication boundary between the resource control and the SMACH state machine.

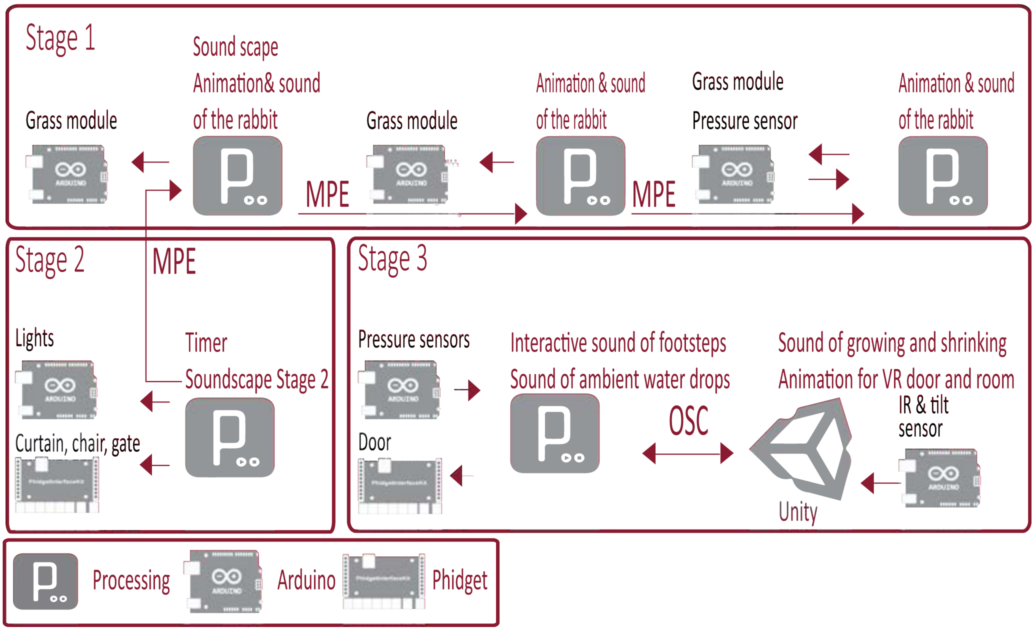


Figure 5.5.2: Iteration 2: Implementation of *Stage 1* to *Stage 3*

Although the Robot Operating System is very suitable for the implementation of a blackboard system, the negative side is that the programming asks for specific technical expertise. Many interaction designers are using Processing (see *processing.org*) for creating prototypes. Motivated by the available expertise in the team, we looked into solutions that will provide a communication interface for the implementation of the story scenario in Processing. Such software solutions are Most Pixels Ever (MPE) library (available from github.com/shiffman/Most-Pixels-Ever-Processing) or Out of Control Semantic Interface (OOCSI) (available from github.com /iddi/oocsi), created at the Industrial Design Department. MPE offers means of broadcasting simple messages between server application and clients. Based on specified frame rate, the server broadcasts a message every N milliseconds to each client. On the other hand, OOCSI implements more specific message broadcasting to a specific channel and is a direct solution for the communication for Processing.

Figure 5.5.2 depicts an implementation of the scenario for Stage 1 to Stage 3. We used Processing to receive the signals from the pressure sensors in Stage 1 and Stage 3, also to control the actuators of the interactive story scenario (grass modules, lights, curtain, chair, gate, door, and the soundscape). The Unity server received the signals from the IR and the tilt sensors, and performed the interaction features with the animations of the virtual door and room in Stage 3. By using the MPE library, messages were broad-casted over the distributed system. To send messages from Processing to Unity we used the Open Sound Control (OSC) message based protocol.

5.6 Conclusions

We presented the redesign of the ALICE installation, which was carried out in the frame of this PhD project. I have to mention that most of the work was conducted in collaboration with many other designers, experts and contributing parties. Figure 5.1.2 shows the team members that joined this PhD work in different stages of the project. Chapter 3 gave guideline on the story elements and the spatial and temporal relations between them. Many of the technologies displayed in the technological state of the art in Chapter 4, were used in the design of the ALICE installation. Figure 5.6.1 gives an overview of both installations, and the difference in the implementation of characters and settings.

Many design challenges were presented in the design iterations described above . We may reflect on these practical explorations, in order to give an answer to our first research objective: *"Identify the design challenges in the process of design and development of interactive storytelling in mixed reality environment"* . With the described design and the reflections on our choices, we identified some of the design challenges. We split the design challenges as ones coming from the issue of *creating a coherent story* that shapes the *user experience*, and *technical design challenges*.

Story related design challenges. In interactive entertainment systems, as games, usually the *rules* are laid out in advance and are explained to the participants. In the ALICE project we created an interactive storyworld, where the participants need to *find out* the parts from the story (storyworld) themselves, and the events are revealed by their actions in the environment. In a virtual reality interactive storyworld the user moves in a created world with her avatar, and has strictly defined abilities (e.g. talk, touch, take, shoot). However, interactive physical environment, as the one in the ALICE installation, does not give pre-defined interaction devices and instructions. Allowing *unguided exploration* in a physical space, creates an additional burden for the design of the immersive environment. Our iterative design showed that the environment has to provide sufficient *feedback and feedforward mechanisms*, which are communicated from the story elements (characters, spaces, events) and will not break the necessary suspension of disbelief. The environment often has to *physically limit* the movement inside the space, or to implement features (e.g. sound or lighting design) that attract the attention towards the wanted direction of the development of the immersive story. Participants would react on the same environment differently: some need motivation to act, while for others the environment has to impose limitations on their actions. The designed environment may also be confronted with unpredicted behavior of the participants, which can lead to fundamental changes in the design. In the design of the ALICE project, we conducted several pilot user test, that help to take a direction in the design.

Technology related design challenges. A physical mixed reality environment gives many creative possibilities for building believable characters and settings. The design of the ALICE installation includes the implementation of robotic and virtual characters, sensing mechanisms, ride, sound design and lighting design. The design team often encounters various difficulties in creating these story elements, e.g. movement of a robotic agent or implementation of specific sensing mechanisms. Often the design has to balance between the wanted interaction in the story and the limitation of the available technology. Usually first are specified the demands from the story and the requirements for the technology has to be specified very precise. Of course it can happen that the requirements cannot be met. For example, if we want to implement natural input for allowing the participant to express easily, it may be difficult or impossible for the current available technology. The richer is the input, the less reliable are technologies that interpret the data. A switch is a very simple input device but also limited in expressiveness. We conclude that the design has to balance between the design of the story and the possible and robust technological solutions.

User related design challenges. The user related challenges are strongly related to interaction design. There are many user centred factors that influence the user experience in a mediated environment, such as motivation, personal involvement and identification with the story. All of these factors have to be taken in consideration into the design process. The user related design challenges will be discussed in detail in the third part of the thesis.

Figure 5.6.1: Implementation of the story characters and settings in the two different installations

6

Tool for Design and Development of Interactive Stories in Mixed Reality

In this chapter we reflect on the design and development process in the ALICE project, we look into the roles in the design team and later we elicit the requirements for a design tool that will support the design and development process. In Section 2.6 we presented the first ALICE installation, and in Chapter 5, we introduced the second ALICE installation. We introduced the design challenges that need to be overcome in order to achieve certain user experiences. The designing and building of the physically interactive environment involved large design and development teams. Firstly, we will reflect on our experience within the ALICE project and we will give a summary of the main issues that characterized the design process.

6.1 Reflection on the Design and Development Process in the ALICE project

The ALICE installation is constantly *changing* and *evolving* as it is created and maintained. The changes are motivated from the research goals, improved design, or practical issues that need to satisfy certain constraints. The ALICE installation was used as a reserch testbed where a team of design and perception psychology researchers evaluated the user experience and proposed

Parts of this chapter appear in Nakevska et al. (2013)

changes and additions to the existing features. User testing often shows that even carefully designed interaction concepts may be inadequate when are confronted with a user.

New interactive story scenarios are introduced or the interactive agents are enriched with new features. The immersiveness of the space is enhanced with enriching the spatial design with static objects and lighting design; and sound design is used to establish appropriate mood in the environment. These changes in the installation cause changes also in the technical implementation. The system need to support the increasing set of technology that implements the interactive story scenario.

The maintenance and development of the ALICE installation is a challenging task, taking in consideration the number of involved components and the diversity of employed software and hardware technologies. The large number of embedded sensors and actuators burdens the development and the maintenance of the equipment over the years: often the implemented hardware and software components get *obsolete* or *damaged*, and have to be replaced. Also, when damaged components are obsolete or not available anymore, that leads to more changes in the system, replacement and reintegration within the system.

It is important that the *flexibility* in the design is extended as far as possible. Usually problems arise in the development process, because the creative team enters the production phase and does not plan all the aspects of the interactive environment. A *premature building* of the actual environment often can be a costly mistake. As we noticed in the previous chapter, user testing may suggest radical changes, which require the designers to be prepared to completely abandon ideas in favor of new more suitable ideas. Once a design works, improvements or incremental changes may be applied to increase or improve functionality over the original design. When the conceptual design is stable, it can be finalized. An *iterative design approach* is also beneficial for the implementation of the constituent hardware and software components.

The building and maintaining of an interactive mixed reality environment, asks for *collaborating effort* from many experts at a time. As the design and development team is changing, often expertise and knowledge about the system is lost. Design ideas and concepts have to be *communicated* over time to newer team members and also between team members with different expertise.

Mixed reality gives a range of possibilities for the design of an interactive environment. The interactive scenario is composed from the interaction features of the agents and settings. Even with a limited number of characters and interaction features, the relations between them may become *complex*. This may lead to *misunderstanding* between the team members, and may increase the time span for the implementation. Even more, the design team needs a playground, to try out more possibilities, before they decide about an interaction feature. Everyone in the team should have a clear picture of the story scenario and the set of required assets, which often has to be communicated to a third party vendor or a producer.

Currently there is no *unified design framework* that can bring together the various expertize and roles that are involved in the process of designing interactive stories in mixed reality. An example of a supporting design framework is a set of media design tools (e.g. Adobe Design Premium

CS) that support a designer to develop content for digital applications. In media design, the designers use specialized set of tools for drawing and editing images, which are building blocks for applications. In this domain, the designers are provided with specific set operators that are relevant for specific problem at given level of abstraction, and are having different views on the same design problem. The problem is that no such consistent set of tools exist for the development of interactive stories in mixed reality environment. The changes in the system usually are done directly in the code. These ad hoc and not structured changes in the system, can introduce bugs in the system and can bring more complexity in the development and maintenance of the system.

In the remainder of this chapter we discuss the requirements for such design framework and we present a design tool that would support the process of design and development of interactive storytelling in mixed reality environments.

6.2 Roles in the Design Team

The production of interactive stories in mixed reality environments demands design and engineering efforts that involve a whole group of contributing experts from various fields, like artists, interaction designers, architecture and civil engineers, and software and electrical engineers. Alcorn (2010) describes the process of engineering and *Theme park design* in the book *"Behind the scenes with an engineer"*. He divides the parties involved in the creation of a theme park attraction into two major groups: "creative" people and "technical" people. The "creative" people start the design of an attraction: *writers* come up with the basic story line; *set designers* are designing the sets, backgrounds and props; *media designers* produce the audio and video materials; other professions are involved in the conceptual phase like: filmmakers, composers, actors, story board artists, art directors, etc. The "technical" people are involved in the estimation of the cost and the feasibility of the proposed design. They carry out the technological implementation: ride control, audio/video engineering, mechanical engineering, and system engineering. The *show controllers* are the most cross-disciplinary and should connect the ride, audio, video, lighting, mechanical, facility and safety. Lighting and special effects designers are also cross-disciplinary involving installation of robust equipment but also selection of location, colors and other artistic and aesthetic characteristics. Apart from the creative and technical teams, these projects engage a whole group of *coordinators*, *planners* and *schedulers*, *estimators* and *financial analysts* and *project managers*. As an example check the diverse team that we had in our ALICE project (Figure 2.6.1 and Figure 5.1.2).

The design teams of interactive storytelling spaces are similar to the ones of traditional theme parks design. Most of the theme park rides are passive experiences, since the visitors cannot interact with the objects or characters they see around. The interactivity is an important difference that we aim to implement in mixed reality storytelling spaces. Therefore, we recognize three groups of contributing parties: (1) interaction designers and creative content experts, (2) technical experts and (3) software and model engineers. These contributing parties and their *roles* in

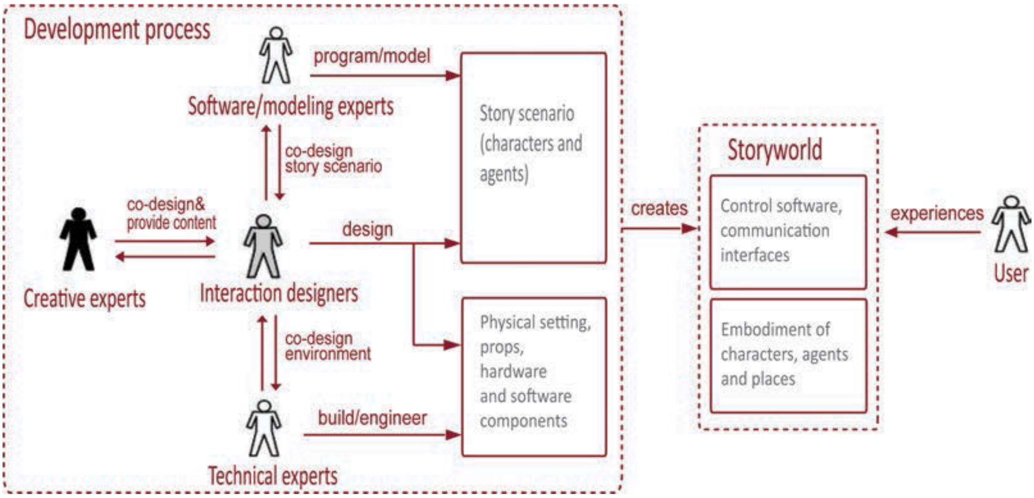


Figure 6.2.1: Roles and activities of the contributing parties in the creation of an interactive storyworld

the creation of the interactive storyworld are depicted in Fig. 6.2.1.

Interaction designers are skilled in creating the interface and interactions for the user, while the creative experts are developing the aesthetic media that contribute to the user experience. *Creative experts* are artists, media designers, film makers, lighting design, directors, and producers. Interaction design draws on concepts of human-computer interaction including people and machines, virtual worlds and a diverse array of objects and behaviors. The designer considers the spaces that fit the story, the flow of the story development, how participants will be led to behave in a space, and the user interfaces. Interaction designers have experience in user centered design methods and are aware of users' abilities and expectations. They define use case scenarios in the interactive narrative and specify the courses of interaction.

Technical experts are the architectural, structural and civil engineers, mechanical engineers, system, audio, and video engineers. Engineering emphasizes the ability to calculate the technical possibilities and resource trade-offs that go into the decisions what can be constructed. They provide the solutions about the spatial design and the needed expertise regarding the implementation of technology. The *software and model engineers* need to put together the whole scenario from the distributed system. They are skilled in concepts from programming and software engineering and are able to express the intended behavior of the storyworld in formal and programming languages. They are familiar with common tools such as editors, compilers and debuggers. In their domain are signal processing, artificial intelligence algorithms, speech recognition algorithms.

6.3 Requirements

The collaboration within such a diverse group of experts requires exceptional clarity in the architectural and spatial design, and the control structure for the story scenario. We define the key requirements for a design framework that would support the design process:

RQ-1: Increase the level of abstraction for developing an interactive story. Storytelling in a mixed reality environment may involve complex scenarios which are distributed over several agents or various hardware/software components. The events that take place are controlled on hardware and software levels. A low-level control will easily distract the creative team from the creation of a coherent story. This requirement ensures that the interaction designers and the creative team will be provided with tools that are more appropriate than low level programming tools.

RQ-2: Provide tools that reflect the different backgrounds and the specific familiar concepts. The involved experts in the creation of a storyworld have different backgrounds and different fields of expertise. Usually they are familiar with different basic concepts; e.g., writers and directors describe a story through characters and drama elements, while software engineers program the interactive story scenario with state machines.

RQ-3: Support for iterative design and development process. An iterative design process approach is essential for designing interactive environments. The interactive environment is continuously tested and redefined. The interaction designers would benefit from simulation of the interaction possibilities before building the hardware. For simple story scenarios it is reasonably easy to maintain the behavior manually. However, as soon as the story scenario grows in complexity it might lead to unplanned behaviors; e.g. the defined rules when a certain event appears is not in line with the intended scenario. A simulation of the interaction possibilities will help the interaction designers to plan better the events and the behavior of agents.

RQ-4: Different views on the system. The team of experts would benefit from documentation of concepts and technical implementations. Different previews of the plan of the interactive story would give a perspective on the system. These views may show the story scenario in temporal order or display a list of available and implemented components.

RQ-5: Evolvability of the story scenario. New story elements or components should be added to an existing story with minimum effort.

RQ-6: Allow for reusable components The existing story elements and components may be reused in another spatial setting or new interactive story scenario. The reusable components can be a low-level hardware or software component (e.g. type of sensor) or higher level story element (e.g. a character) realized by combination of hardware and software.

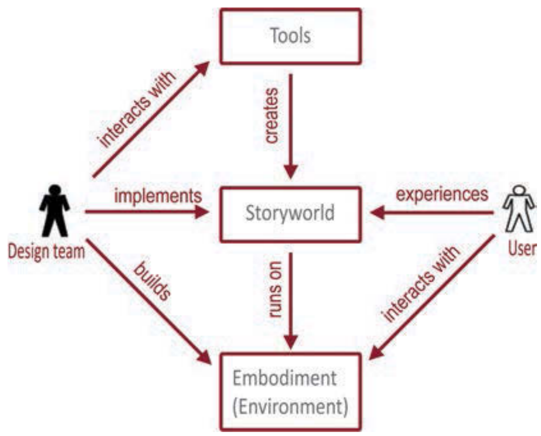


Figure 6.4.1: Overview of the design domain

RQ-7: Ease of use The design tool should be easy to use for experts that have no technical background. It should be accessible for story writers as it is for software engineers.

Having derived the requirements, we look for engineering approaches that cater for flexibility and evolvability of the system, while providing for early clarification of the implementation of the interactive narrative scenario and abstraction of the low level complexity. One such advocated approach is *model-driven engineering*, where *models* play a central role as means of communication between the involved design and development parties and provide for a flexible design framework in which the behavior of the system can be simulated and validated before expensive prototypes are built.

6.4 Model Driven Engineering

A *model* depicts the structural elements and their conceptual constraints within a domain of interest. The various entities, their attributes and relationships are defined in the model. Kent (2002) proposes organization of the modeling 'space' and discusses different kinds of mappings between models. Distinction is made between *platform independent* and *platform specific models*: *platform independent models (PIMs)* are formal specifications that abstract away technical details, whereas *platform specific models (PSMs)* are models for a target platform. The interactive system is developed by refining models starting from higher and moving to lower levels of abstraction until code is generated. Refinement is implemented by transformations over models. Mappings may be defined between models in the same language (model translation) and between models in different languages (language translation).

The models are artifacts that need to be maintained along with the code. The benefits of having models need to be maximized and the effort required to maintain them to be minimized.

Kent (2002) argues that more sophisticated tools are required to maximize the benefits of having models. Tools can help the well-formedness of the models, will support mappings between models, model driven testing, and managing the software engineering process.

Figure 6.4.1 depicts the design domain for interactive storytelling in mixed reality: the design team interacts with tools to create a storyworld that can later be experienced from an user. The user interacts with the embodied interactive environment. In the reminder of this chapter we present the steps towards such tools, that would support the design team.

6.5 Related Work

Mixed reality

In the mixed-reality domain, several frameworks, tools and notations have been proposed (O'Connor and Hughes, 2005, Grimm et al., 2002, Dubois and Gray, 2008, Charfi et al., 2007, Didier et al., 2009). These proposals address specific aspects in the design and development of mixed interaction systems in order to express, simulate, and validate certain properties of the system. They provide notations that model key elements of mixed-reality interaction, which support the reasoning about combined physical and digital worlds. ASUR (Dubois and Gray, 2008) highlights key interaction elements to support the design of the mixed interactions, while K-MAD (Charfi et al., 2007) is used to describe the activities on a higher level for the purpose of requirement and task analysis. MIRELA (Didier et al., 2009) employs timed automata to simulate and verify various reachability properties of the timing behavior of the system in order to assess the user experience. These approaches tend to build a complete combined model of the (timing) behavior of the components of the environment and the interactive scenario. O'Connor and Hughes (2005) present a scripting engine and an XML-based language that allows an author to interface human interaction with the other elements of a mixed reality experience. The AMIRE project (Grimm et al., 2002) implements a software system that allows content experts to easily design and implement mixed reality applications without detailed knowledge about the underlying base technologies of mixed reality. However, these approaches and software systems do not implement high-level concepts for interactive storytelling applications.

Interactive storytelling

Text-based domain specific languages (DSLs) allow definition of an implementation in high-level semantics, while being parseable by a computer at the same time. SAGA language is created specifically for a domain expert in story design, which should be natural to use and to improve their effectiveness (Beyak and Carette, 2011). Inform 7 is a language for creation of interactive fiction (Walter and Masuch, 2011, Ardolino et al., 2014). This text-based approach lacks visual support in the process defining the story scenario, such as storyboards or sketches.

There are many projects that support the authoring process of interactive storytelling applications. Several interactive drama engines are produced: Erasmatron and Storythron (Crawford, 2012) are Interactive Storytelling Engines that implement actors, verbs, stages, props, events, groups, numbers and flags. IDtension (Szilas, 2003) implements a model that is based on the five fundamental concepts (goals, tasks, segments, obstacles and values). FAtiMA is an authoring tool for emergent narrative agent architecture (Kriegel et al., 2007). Scribe is an authoring tool that is used to create interactive dramas (Medler and Magerko, 2006). DraMachina is an authoring tool that is based on text editing, the author describes the narrative elements and specifies the relationships between them, for composing an interactive fiction (Donikian and Portugal, 2004).

However, all of the mentioned engines and authoring tools are designed to build interactive storytelling in virtual reality environments, they do not support physical actuation and implementation of hardware components. We contribute to the field of interactive storytelling in mixed reality, with creating a design tool that would support the authoring and design process of interactive stories in mixed reality. In the following, we describe the authoring tool *Tell me a story!*, which supports the design process with textual representation of an interactive storyworld, and allows easy integration of variety of technologies that can be used in a mixed reality environment. We aim to satisfy the requirements that we presented in Section 6.3.

6.6 *Tell me a story!* a Tool for Authoring Interactive Stories in Mixed Reality

It is important to consider how telling a story in a three-dimensional interactive space is different from telling a story in text, oral forms or movies. Traditional storytelling conveys the events in imaginary words and images; whereas an immersive story is told in three-dimensional space using architecture, design, and material elements. The plot of the story develops through the journey that takes place through different design spaces and elements (Lukas, 2012).

An author of a classical linear story writes the story, including description of characters and dialogs. The authors of an interactive storyworld also need to provide a description of a story *scenario*. This involves a description of the scenery settings, the characters, important objects, key events and the role represented by the participant. Usually designers create a story outline which is refined into a design concept. In order to give structure in this process, we considered the levels of abstractions that can apply in the domain of interactive storytelling in mixed reality environments. We derived the important levels of abstraction based on the previously defined story elements (characters, agents, places, events) and the relationship among them.

6.6.1 Levels of Abstraction

Figure 6.6.1 depicts the levels of abstraction for the design of interactive stories in mixed reality environments. On the lowest level is the direct control over the hardware and software; e.g.

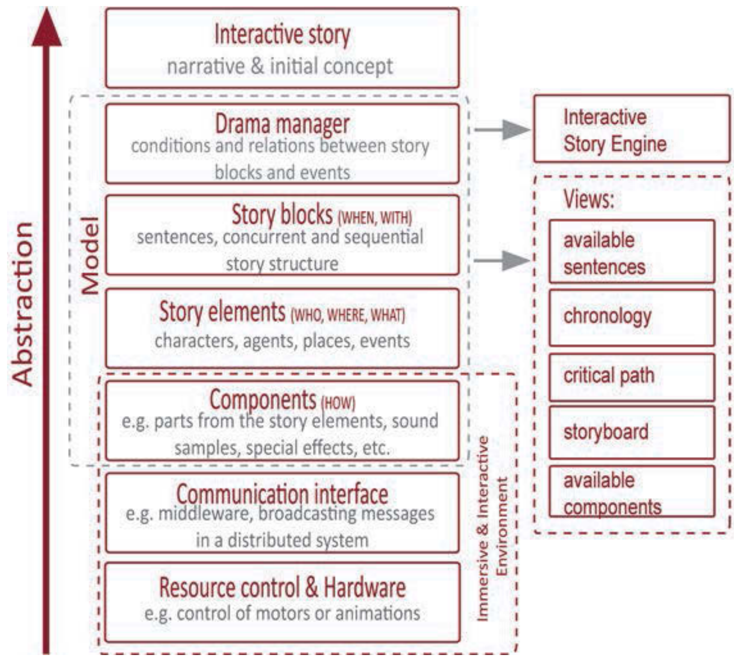


Figure 6.6.1: Levels of abstraction in the design of Interactive Stories in Mixed Reality and views that are provided

access to motor control or virtual reality animations, and requires extensive technical skills. A distributed system also asks for implementation of a *communication interface*, such as middleware or message broadcasting. *Components* are parts of the story elements; e.g. control of trajectory of movement, special effects, sound design or lighting. These separate building blocks compose *story elements* as characters, agents, places and events. *Sentences* allow definition of the relations between agents, places and events; whereas *story blocks* define the story structure with concurrent and sequential temporal relations of the sentences. A high level control like a *drama manager* will help defining the conditions and relations between triggering separate story blocks or events. Ultimately, on the topmost abstract level is the *story*; the design team is inspired by a narrative and needs to transfer the initial concept into a materialized storyworld by using the lower levels of abstraction.

The usage of high level abstraction shields the creative team from the complexity of the implementation; the design team defines the elements of the story scenario without having in mind all the technical details. The technical, low level, components of the system, are introduced later in the design process, as agent's modalities.

The *Tell me a Story!* tool implements a GUI which leads the user through several tabs: *who, what, where, with, when* and *how* (Figure 6.6.2). The iterative design process is supported with *Interactive Story Engine*, which simulates the interactive environment with a textual presentation.

It also implements several views of the model: *available sentences*, *chronology*, *critical path*, *storyboard* and *available components*. We will further explain each of them in the following:

6.6.2 Who: Agents

In Chapter 3 we described the story elements of an interactive story, such as characters and events; we noted that the *agents* trigger the events in the narrative, whereas *characters* are more important agents that stretch beyond the actions, as they posses traits, motives, and personality. In the *Tell me a Story!* tool we implemented textually described *agents*, while their physical appearance is portrayed with sketches and drawings. In the first brainstorming phase, the design team decides about the implementation of agents, in the tool they are introduced with textual description and sketches, drawings or pictures.

The role of the participant also needs to be defined. In the ALICE project we explored how to implement an interactive storyworld with only one participant, also the *Tell me a Story!* tool allows defining a role for only one participant at a time. Introducing more than one participant in the interactive environment will impose the questions: How a particular participant will be recognized? How to design the interaction features for each of the participants? How to engage more participants into interaction in the same time? The *Tell me a Story!* tool does not support design of story scenarios which involve many participants, although it can be extended to define multiple roles to multiple participants.

6.6.3 What: Events

What deals with identifying the activities of the participant or the environment itself. The events need to fit in a computable expression, such as detecting a location of the participant or performing an action. Events can be triggered by certain type of actions by the user or they can be pre-programmed and timed according the story scenario.

6.6.4 Where: Place

Where deals with identification of the locations in the storyworld. A *place* represents a physical real world location; where participants can move around, go in and out. Often for the narrative scenario important information is the exact position of the participant or a character. Each *place* has a name and a sketch or drawing used to represent it.

6.6.5 With: Sentence

Sentence represents a narrative step that can happen in the storyworld. The sentences describe the events that can happen in the storyworld and who is involved in each event. A sentence defines *subject (WHO)* can be the user or an agent, *verb (WHAT)* is the performed action and

Figure 6.6.2: Sentence defined in the tool *Tell me a Story!*

object (WHO) is the agent that will do or detect this action (see Figure 6.6.2). Also the *location (WHERE)* for the subject and the object are defined within the sentence, in some scenarios they are not at the same location; i.e. action in one place will make changes in other location. The *set of sentences* give the available set of actions that can be observed or conducted by the interactive environment. The authors define the order and conditions when these events can be executed and what type of modalities are involved in each event.

6.6.6 When & If: Drama Manager

The *drama manager* (see Figure A.0.1, Appendix A) allows defining the story structure in a form of *story blocks* and the conditions in a form of *guards* for each story block or a specific event.

When: Story Blocks

Interactive story "retells" a narrative through the triggered events in specific temporal relations. In Section 3.6 we referred to the principal categories of time (order, duration, frequency) in a narrative defined by Genette (1971), from which order considers the relation between the events

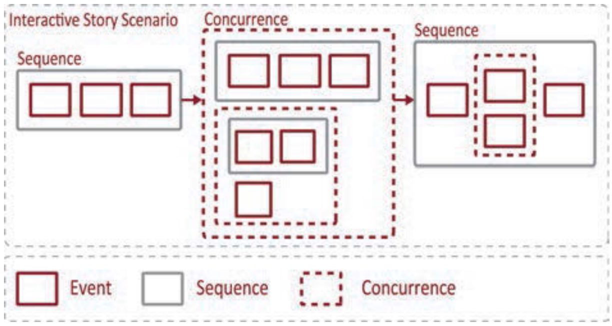


Figure 6.6.3: Nested story blocks

of the story and the sequence in which they are related. The story blocks determine the *temporal order* in the story scenario.

Sequence. A *sequential story block* maintains the order of execution of events. Events added in one sequence block are executed only in the defined order. A *critical story path* is defined with marking the events that must happen before next events are allowed to be triggered. Concrete *delays* between two separate events are modeled with a precise quantitative measure of time in milliseconds.

Concurrence. In a *concurrent block* all the events are executed simultaneously, it terminates when the defined condition in the drama manager is fulfilled.

Additionally, *iterator* story block is used to allow looping through an event or story blocks until successful conditions are met. Each type of story block can contain more from the same type of story blocks, visualization of such nested story blocks are presented in Figure 6.6.3. A concurrent story block may contain previously defined sequence, concurrency and events, and similar it is for a sequence story block. The basic relations between temporal intervals (equal, before, meet, overlap, during, start, finish) can be defined with the combination of the story blocks and introduction of delays.

If: Guards and Conditions

Related to the events, *variables* are defined to keep the data of interest in order to model the scenario. These variables are used to model the conditions and are referred to as *publish* and *subscribe data*.

A *guard* can be defined per event and story block, it determines when the event or the story block can be executed. The guard is defined as a logical formula of previously defined *conditions*. The conditions refer to the previously defined subscription data, which can be flags (boolean variable), comparison of subscription (<,>,!=,==) with a value (integer, float, string), or comparison between two subscriptions. The use is described in the case study in the next chapter.

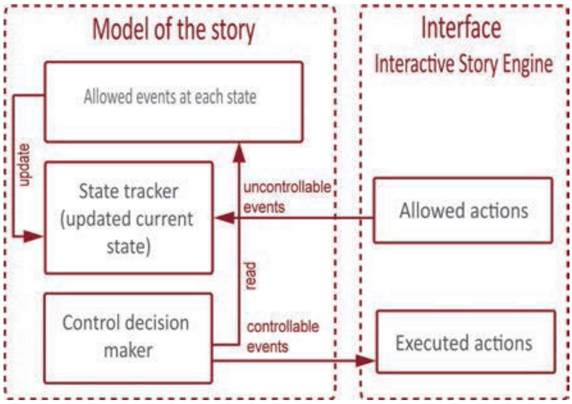


Figure 6.6.4: Interactive Story Engine

6.6.7 How: Components and Modalities

As already discussed in previous chapters, there is a wide range of available hardware and software technologies that can be used to implement interactive stories in mixed reality environments. Actions from the user are observed by implementing different sensing mechanisms. The modalities are defining the capabilities of the characters and props in the story: embodied actuation, sound, animation, light, or special effects.

In the previously defined *sentences*, each event is linked to the agent that produces the event or observes it. And for each event produced from the environment the actuation modalities are defined: embodied actuation, sound, animations, light, special effects, publishing information. For each event triggered from the user, the authoring team needs to define an appropriate observer (proximity, sensing, see or hear). These sensing mechanisms ask for implementation of advanced computer vision or speech recognition algorithms, and implementation of specialized hardware. In section 4 we gave overview of the sensing technologies, the modalities and the approaches in implementing them.

The *Tell me a story!* tool allows definition of the hardware and software components with their attributes (see Figure A.0.3, Appendix A). For example, a sound sample is defined with file name, volume, description, the type of sound (ambient, speech, music), the controller (DMX controller, sound player, game engine), and if it is played once or in a loop.

6.6.8 Views and Interactive Story Engine

Views are necessary to represent each of the different aspects of concern and to fulfil different roles such as verification of correctness, human understanding through visual interpretation, and code generation. The views that are provided by the *Tell me a story!* tool were previously shown in Figure 6.6.1 and are explained in the following:

Interactive Story Engine. In an iterative design, prototypes are built to test a concept or process. A simulation of an interactive prototype would help the design process with preview of the imagined interactive story scenario. The *Interactive Story Engine* helps the designer to simulate the interactivity of the defined story scenario. Figure 6.6.4 shows the components of the Interactive Story Engine, Figure 7.3.1, presents the user interface.

The engine displays the *allowed actions* that can be triggered. A database container keeps information of the *allowed events at each state*, whereas a *state tracker* is updated about the current state. *Uncontrollable events* refer to sensory information or user interaction, while *controllable events* model activities over which the control software can perform an action, like actuator interaction. The *control decision maker* has the model of the defined scenario together with the allowed events of the current state. It produces controllable events and displays the followint available actions. The presentation of these controllable events and allowed actions is textual.

Storyboards. Storyboards are common tool used in film making and theme park design, they give overview of the possible development of the story in a sequential manner. In the *Tell me a Story!* tool, with each sentence, the authors upload a sketch of the scene which depicts the event. The storyboard displays these sketches as the plan of the story scenario is defined (Figure A.0.2).

Chronology and the Critical Path. Chronology expresses the narrative line, illustrating the branching tree defined with the sequential and concurrent story blocks. The *critical path* lists the events that must occur in order to successfully reach the end of the story.

Available sentences and *available components* are list of the defined sentences and components in the *Tell me a Story!* tool.

The story defined in the *Tell me a Story!* tool has to be transformed into executable code that controls the hardware and software elements and allows for interaction with user.

6.7 Execution Environment

The usage of the abstract elements in *Tell me a Story!* eases the learning curve and helps broader range of experts meet their needs, i.e. the environment performs the intended interactive story scenario. However, the defined story scenario with *Tell me a Story!* should eventually be transformed into executable controller for the interactive story scenario. An execution environment has a goal to provide for deployment of interactive environments used by users.

The *Tell me a Story!* tool facilitates the definition of a platform independent model of the interactive story scenario, saved in a *relational database*. The definition of platform independent model helps the design team to decide about the requirements, structure and behavior at different levels of abstraction. Model transformation is used to support the software engineering process, it may include transformations from a more abstract to a more concrete model (e.g., from design to code).

The model defined with the *Tell me a Story!* tool, kept in a relational database, is used to generate code for the execution environment, instead of writing it. We use *stored procedures* to select the story scenario defined within story blocks and the drama manager. This selected structure of the story scenario can be mapped into XML or code in a specific programming languages. The code generation is specific for the implementation platform (programming language, communication interface, etc). An example of concrete implementation platform is presented in the next chapter.

7

A Case Study: Eat me, Drink me

The *Tell me a Story!* tool was developed in parallel with the ALICE installation. We discussed the design process of the ALICE installation in Chapter 5. The conclusions from these observations gave guidelines for the proposed design tool *Tell me a Story!*, described in Chapter 6. We presented its levels of abstractions and the intended use for each of it. In this chapter, we use the "Eat me, drink me" stage as a case study to demonstrate the usage of the *Tell me a Story!* design tool and its impact on the design process. Since we noticed that the design process is also altered with the usage of the tool, we deliberate on each of the design phases, we demonstrate how the design tool is integrated, and we reflect on the improved and better structured design iterations.

7.1 Design Iterations

The *"Eat me, drink me"* stage from the ALICE project is based on part from the first chapter from the novel "Alice's Adventures in Wonderland" Carroll (1865). The summary from this part of the novel was also presented in Section 2.6.3:

> *Alice enters a room with many doors, which are all locked. She comes upon a little table made of glass on which lies a golden key. She finds a tiny door which fits the key, and from there she sees a beautiful garden, but she is too tall to enter. She notices a bottle labeled 'Drink Me', she drinks from it and she becomes very small: the right size for going through the little door. But she noticed that she left the key on the table and she can not reach it. She notices a cake labeled 'Eat me'; after she eats it, she becomes big*

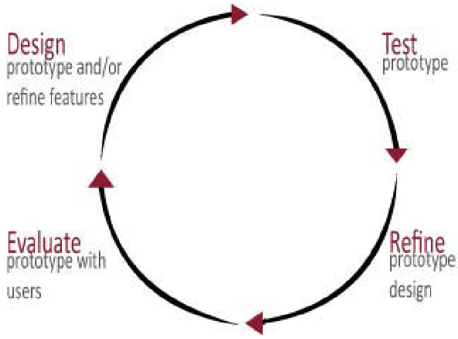


Figure 7.1.1: Iterative design process

and she grabs the key. By drinking from the bottle, she shrinks again. Eventually, she manages to have the appropriate size to enter through the tiny door.

Two main design objectives regarding the user experience were distinguished: 1) how to achieve the participant to feel that is getting bigger and smaller in relation to the environment and 2) how to allow the participant to interact with the story. We used an iterative design approach, which involves prototype design, testing and evaluation with users was used (Figure 7.1.1). The user tests revealed new insights, which often asked for improvements. Post-hoc, we split the work conducted in several years, into four major iterations:

- *Iteration 1.* The first design iteration was implemented in the first ALICE installation. This stage was designed and constructed as a five sided Cave Automatic Virtual Environment (CAVE). It was described earlier in Section 2.6.3 and presented in Figure 2.6.3. The implementation of a CAVE gave design directions and limitations for the second ALICE installation.
- *Iteration 2.* In the second iteration, the CAVE was rebuilt with a new software platform and at a new location. The obsolete hardware components were replaced with newer ones. A pilot test was performed. We observed the behavior of the participants and we looked at the possible improvements of this stage. This iteration was explained in Section 5.4.
- *Iteration 3.* The VR room was redesigned, different types of growing and shrinking animations, including new VR models and textures of the VR room, were tested. Iterative prototyping aimed to overcome the challenges of five sided CAVE projection, difficulties were encountered in the scaling of the VR room and the perceived perspective on many sides at one time.
- *Iteration 4.* After decisions were made about the platform and the main animation, the design team reviewed the possibilities how to engage the participant to interact with the story. The story gave guidance for the possible interaction scenarios, we reviewed the

issues concerning how to provide feedback for the actions of the user and how to implement feedforward information that will guide the user through the preferred outcome from the story scenario.

In the reminder of this chapter, we discuss the last (fourth) design iteration, we reflect on the design and development process and we demonstrate the usage of the *Tell me a story* tool in the design process. We distinguish five phases in the design and development process: *conceptualizing, pre-production, production, post-production* and *evaluation* phase, as depicted in Figure 7.1.2.

7.2 Conceptualizing phase

In the *conceptualizing phase*, early decisions about the story concept are made. The starting ideas need to be defined in details if they can be done and at which costs. The team develops *flowcharts*, character *sketches* and other visuals to further refine the interactivity and the look of the spatial setting and agents.

Although, *Stage 3* preceded other design iterations, the redesign of the interactive features required the design team (interaction designers and project managers) to go back to the novel "Alice's Adventures in Wonderland" for new inspirations. We also looked into movies, cartoons and other similar attractions which are inspired by this narrative. The design team considered creating an interactive storyworld which is inspired by the narrative, rather than creating it in strict accordance with the narrative; by giving it an artistic/playful twist. The design team put forward several design challenges:

- How to *engage* the participant in the story? Can we make the aim of this stage clear to the participant, without verbal explaination beforehand? How does the participant know which are the actions she should take to finish the stage?
- How to enhance the *immersiveness* and *responsiveness* of the environment? Which are the modalities and design principles which will contribute to more immersive experience?

Interaction designers gave several proposals for a story scenario, that involved defining the story characters, agents, their actions and dialogs, and places where they are located. Storyboards and sketches, depicting the possible story scenarios, were produced (see 7.2.1. The design team aimed to add feedback on behaviour (implicit guidance) and feedback on actions (explicit guidance) to create a more engaging experience. We considered adding characters that can enrich the setting with their presence and engage the participant in the environment, although there are no characters in this part in the original novel. The changes of the mood in the space can give hints on the development of the story; whereas the characters can give direct feedback about

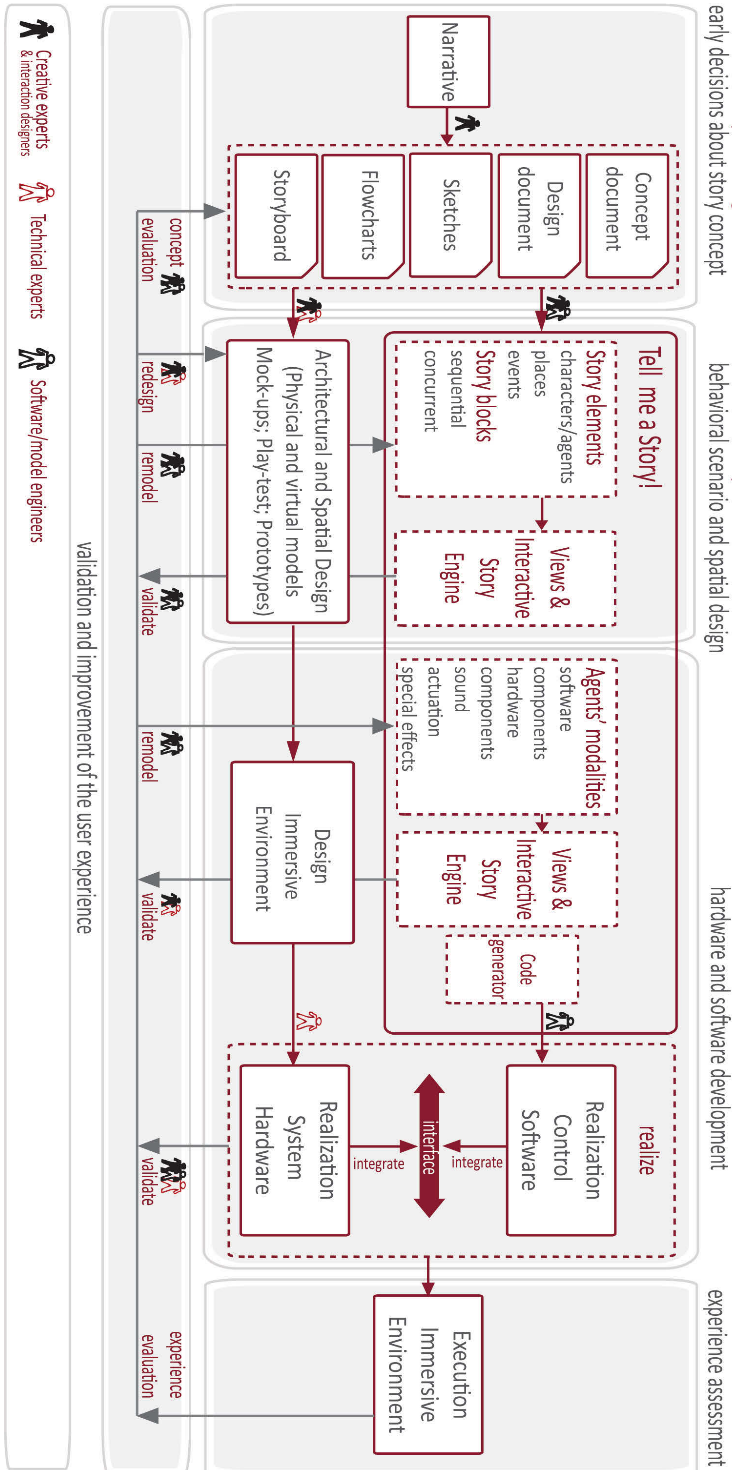


Figure 7.1.2: A design process of developing interactive story scenario, with using the *Tell me a Story!* design tool

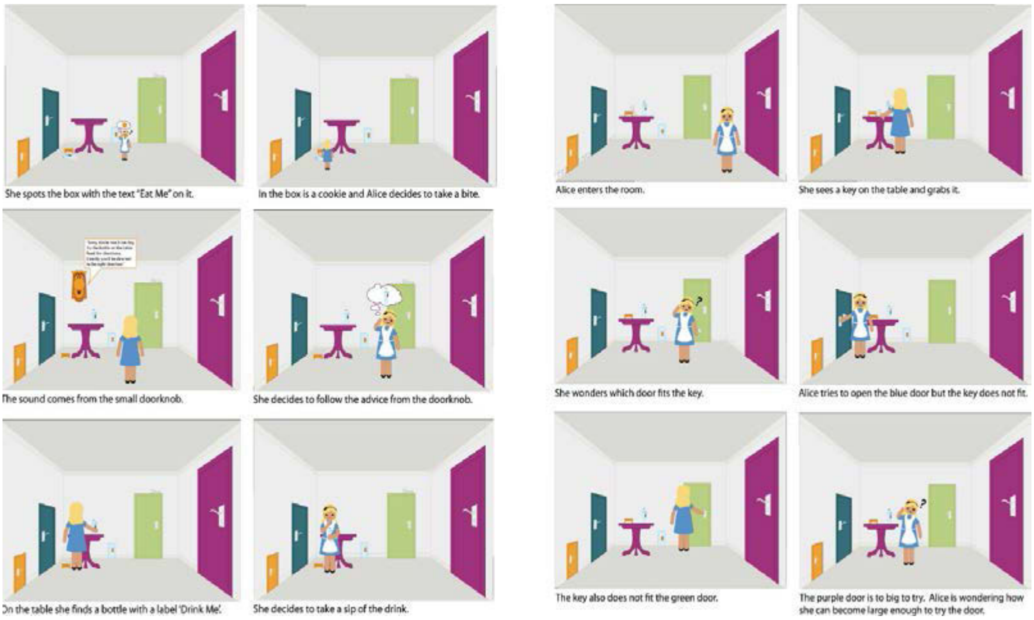


Figure 7.2.1: Part from the storyboard generated in the conceptualization (brainstorming) phase

the actions of the participant. We came up with several interaction features, yet not completely defined:

- *Virtual garden, The White Rabbit, and a key.* The attention of the visitor is attracted to the 'special' door and a beautiful garden where the White Rabbit reminds her to hurry up. However, there is a key to this door that should be found.

- *Talking doorknob and an outside "narrator" voice.* A talking doorknob would give feedback related to the relevant size of the participant and the door and the taken actions to finish this stage and to continue further; whereas the narrator voice is an observer of the behavior of the participant and gives implicit guidance by giving comments.

- *Sound design.* Sound is an important modality to enhance the immersiveness of the physical space. We considered the sound types (ambient, music, speech) and their properties, presented in Section 4.5.

The design team reviewed the possible scenarios, which resulted into defining the necessary story elements and the structure of the story scenario. Having the preliminary decisions, the design team continued with the pre-production phase to fully define the story scenario.

7.3 Pre-production phase

In the *pre-production phase*, the spatial design and the overall look of the immersive storyworld is decided by the design team. The participant's role in the narrative has to be described: how the participant will affect change in the interactive environment; how the user will be motivated to experience the interactive story; what is the nature of the elements that the user will encounter. The team also needs to decide about the structure of the narrative: the starting place in terms of user experience, the possible end points and the major units of organization of space and time. The interactive story scenario is influenced by the various design and implementation decisions, such as implementation of the hardware control, or semantics in the interaction design, the choice of the medium, e.g. virtual reality projection or embodied robotic character.

The *Tell me a story!* tool can be used from early pre-production to end of production. In pre-production phase, the agents (who), the events (what) and the places (where) are defined. The functions and features of each of the agents are refined during the design process. The design team reconsidered the spatial and interaction design for the "Eat me, Drink me" stage. The complete interactive concept was we present in Section 5.4

We described many separate interactive features that can be modeled in different levels of abstraction. The team may have clear idea of what they want to achieve, but the implementation may differ from the intentions. For instance, we have envisioned many feedback and feed-forward replies from different characters (door, rabbit, narrator); it may happen that all of the replies will be triggered at once if the behavior is not restricted. This type of failures in the interactive scenario may negativelly affect the user experience and the sense of presence.

7.3.1 Design process guided by the *Tell me a Story!* tool

Before the design team continues with production of each of the assets needed for the story scenario, the interactive scenario has to be finalized and clarified. The tool *Tell me a Story!* is used in this phase of the design process, which allows to model the interactive scenario and change it, before expensive prototypes are built.

Who: Characters

The *characters* represented by *agents* and *spatial settings* were conceptualized in the first phase: the White Rabbit, a talking doorknob, a beautiful garden and a key from the 'special' door. Each of the characters, features of the spatial setting or props are represented by an *agent* in the *Tell me a Story!* tool. For instance, the White Rabbit, the doorknob and the garden are incorporated in the virtual room with many doors, so they are defined in the tool through the agent named *VRRoom*. Other agents are: *CookieBox, Bottle* and *Key*.

What: Actions

The *actions* of these characters also needed to be specified: talk, wave, show, open, close, etc; and the expected actions of the participant that we want to observe: step, approach, take, drink. We defined them in the *Tell me a Story!* tool as events triggered by the environment or events expected from the participant. For example, the environment can observe the actions of the participant: *Eat, Drink, Step, HoldKey, LeaveKey*; whereas the agent *VRRoom* can perform the events: *GetBigger, GetSmaller, KeyAppears, KeyDisappears, ShowVRGarden, CloseVRGarden, WalkingFeedback, StandingFeedback, LockedFeedback, CloseDoor, OpenDoor*. In this story scenario only one place is defined, named *Room*.

With: Sentences

Having defined the possible events of the interaction scenario, they are linked in a *sentence* with the agents that can observe or produce it. For each sentence is uploaded a picture that represents the particular event with the involved agents and places. Figure 6.6.2 shows the definition of the sentence *VRRoom {Room} TooBig*, referring to the event the doorknob says *"Sorry, you are way too big"*; a storyboard image depicting this interaction feature is uploaded with the sentence. Also the list of the available sentences is visible in the With tab. The participant is represented in this storyworld as *Alice*. For instance, in the sentence *"Alice {Room} Eat CookieBox {Room}"*, *Alice* is a notation for the participant, while *Eat* is an event produced by the participant and observed by the agent *CookieBox*, both participant and agent are located in the same place named *Room*.

When: Story blocks

The defined sentences are organized in *story blocks* that can be executed in a *sequential* or *concurrent* order. The user interface of the Drama Manager is depicted in Figure A.0.1 in Appendix A. For example, the event *HoldKey* happens when the participant takes the physical key and is always accompanied with the event *KeyAppears* i.e. a virtual key appears on the virtual small door. These two events are coupled into a sequential story block, named *HasKey*, which contains the sentence *"Alice {Room} HoldKey Key {Room}"* (annotated that must happen) before the second event *KeyAppears* is triggered by the interactive environment. It is similar with defining concurrent story blocks, which allow events to be triggered in the same time. For example, when the participant steps in the space, the environment gives appropriate feedback depending on the position where she steps or the number of produced steps. The concurrent *FeedbackSteps* story block consists from the events *ShowGarden, CloseVRGarden, TooBig, DoorknobLocked, WalkingFeedback* and *StandingFeedback*; each of these events can happen in the same time. However, we need to define the conditions when each of the events in the concurrent storyblock are allowed to execute.

If: Conditions and Guards

The conditions for each event and story block are defined in the *Drama manager*, Figure A.0.1. First we need to define the variables that allow to define the conditions, such as *flag_gardenVisible*, *flag_HoldKey*. For each event we need to define to which variable they are subscribed and to form the *guard* as a logical expression. After the event is executed it can also publish new values for the variables. For example, to show the VR garden, the condition is the participant to hold the physical key and to be close to the projected door; the guard for this event is described as "*(flag_holdKey* AND *NOT(flag_gardenVisible)* AND *(signalOpenVRDoor == 1))*". To each of the events and story blocks a guard can be attached.

Interactive Story Engine

The Interactive Story Engine is an interactive preview of the story scenario, which aims to support the iterative design cycles. Having defined the story blocks and guards with subscriptions and published values, an abstract plan of the interactive story scenario is defined, even before deciding how exactly the agents will be implemented. The design team can use the *Interactive Story Engine* to check the validity of the planned interactive scenario. The *Interactive Story Engine*, displays textually the allowed and executed events in each moment as the participant would interact in the immersive environment (Figure 6.6.4). As the designers try out different discourses in the story scenario, they can have an impression of the scenario, to recognize if there are omissions in the design in a very early stage. As the conditions and guards are changed in the *Drama manager*, the scenario is immediately changed and can be checked again with the *Interactive Story Engine*.

7.3.2 Architectural and Spatial Design

In parallel, as the interactive scenario is defined and tested with the *Tell me a Story!* tool, the design team builds physical and virtual models, mock-ups, play-tests and prototypes of the props and settings. A physical prototype of the interactive environment or parts from it would demonstrate how the project actually operates. Such prototype may reveal flaws in the concept or in its functionality, and often the initial concept has to be redefined. The architectural and spatial design, together with the modeling of the interactive story scenario constitute the pre-production phase. This phase provides (semi) finalized interactive scenario, before it is further materialized in the production phase.

7.4 Production phase

Production is the main stage of development, when assets and source code for the interactive environment are produced. The assets of the storyworld have to be produced completely: artists and media designers are developing assets as 3D models, sound designers develop sound effects,

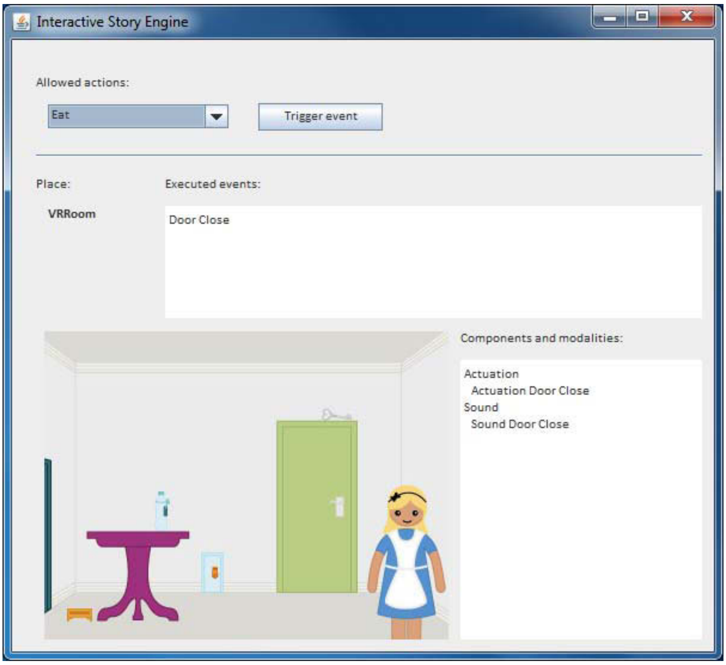


Figure 7.3.1: The user interface for the Interactive Story Engine

composers compose music, and stage designers are building the physical settings. To allow interaction in the physical space, sensing technology has to be embedded in the objects and settings. The hardware has to be assembled and the embedded software has to be implemented. The electrical and software engineers have to incorporate the features demanded by the story scenario, e.g. for the detection of movement, pressure sensors are installed to cover the floor.

Figure 7.4.1: The 3D models for the talking doorknob, the White Rabbit and garden

The design of the *"Eat me, drink me"* stage required production of virtual reality models of the characters (Figure 7.4.1) and recording and processing of the sound for their speech. The 3D model of the VRroom agent were designed and animated in 3DS MAX and imported into the game engine Unity. We used Blender to design and animate the virtual 3D characters that were also imported into Unity.

```
1       if ((flag_holdKey == 1) && (flag_gardenVisible == 0) && (signalOpenVRDoor == 1)) {
2           flag_gardenVisible = 1;
3           countWalking = 0;
4           VRDoorOpen();
5      }
6
7      void VRDoorOpen() {
8        OscMessage oscMessage = new OscMessage("open");
9        oscP5.send(oscMessage, myRemoteLocation);
10       print("VR Door should open and rabbit waves");
11       output=append(output, str(millis()/1000) + " VR Door should open and rabbit waves");
12     }
```

Figure 7.4.2: Example of generated code

Each of the previously defined events is related with the agent that does or observes the action. If the event is produced by the environment, the modalities for the agent should be specified. If the event is produced by the participant, an observer has to be defined. As the physical and digital components are built, they are also specified in the *Tell me a Story!* tool, as *components*. The components are defined by the parameters: type (e.g. sound can be ambient, music, speech), controller, name, played (in loop or only once), volume, speed, file name and description. The components define the methods that are called for the execution of each event. In Appendix A), Figure A.0.3 on the left side are modalities defined for agent per event, whereas on the right side the components are defined.

Having defined each of the agents with their modalities, the design team may use the *Interactive Story Engine* to check the interactive scenario. The engine presents the interactive scenario textually, with the added information about the triggered modalities per each event.

Once the interactive scenario is defined and agreed upon, the model defined in *Tell me a Story!* has to be transformed into an executable code. The code generation is related with the choice of the programming language and a communication interface. We discussed the communication interfaces in Section 5.5, a schematic overview of the used software in "Eat me, drink me" stage is depicted in Fig. 7.4.3. Processing was used as a main control panel for the interactive story scenario, which receives input from the IR and tilt sensor through Unity and Open Sound Control protocol.

A code generator parses the defined interactive scenario and produces a skeleton for the Processing control panel. Figure 7.4.2 shows an example of the generated code, using the guard defined in the *Drama manager*. Also the values defined in the *Drama manager* as published are translated into code to change the value(line 2 and 3). The function *VRDoorOpen()* (line 7-1) is added in the *Tell me a Story!* tool, through a definition of an event handler. The code generation is specific for the implementation. It facilitates the production and secures that the simulated scenario by the *Interactive Story Engine* is produced as executable code. However, so far we managed to generate only a skeleton of the code, while the functions that are specific to platforms have to be added manually.

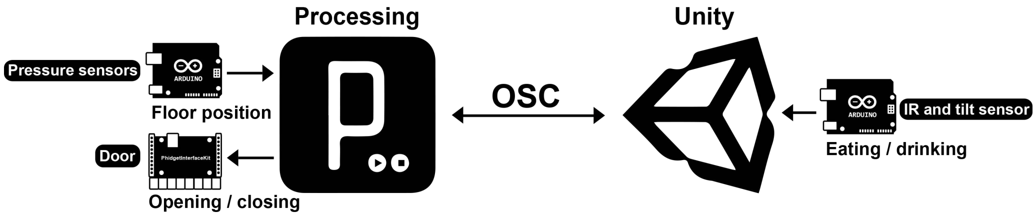


Figure 7.4.3: Schematic overview of the software (OSC:Open Sound Control).

7.5 Evaluation phase

During the iterative design process, users may be involved in each of the phases, by testing the first prototypes or to think along with the designers about the defined interactive scenario. In the *Evaluation* phase users can be involved in the testing of the physical (semi)working prototypes. Also the experience that will emerge from that interaction, can be assessed.

Problems in the hardware and software are reported in this testing period. The evaluation of the user experience can lead to redesign of parts from the environment. The interactive scenario may be altered, in order the user experience to be enriched. The creative team can re-evaluate the concept and make changes, which will ask for redesign of the spatial environment and remodeling of the story elements defined in *Tell me a Story!*. The re-designed interactive story should be validated again and to be brought to production.

In Figure 7.1.2 are shown the steps where the design team can redesign, remodel and validate the interactive story scenario and the environment. Each addition of new element, or changes in the existing ones are reflected on repeating the steps of the design process. Every time new features are added, subtle changes can produce unexpected changes in different parts of the interactive scenario. Hence, regression testing has to be performed with every change. The environment is tested and interaction features and safety issues have to be checked. Any safety failures in the environment have to be fixed before users are involved. After all the tests by experts are finished, the interactive environment can be experienced by users.

7.6 Conclusions and Future Work

In Section 6.3 we listed the requirements for a design tool that will help the process of building interactive stories in mixed reality. Having described how the tool *Tell me a Story!* is used, we may reflect on the previously given requirements(RQ1-RQ7) that the tool should satisfy, Section 6.3.

Increase the level of abstraction (RQ-1) and usage of existing tools and familiar concepts (RQ-2): The tool increases the level of abstraction by allowing the design team to define the story scenario with high level concepts such as agents, sentences and story blocks and to have a view on the possible story paths with chronological view and storyboard. The design team can test the designed interactive scenario, without the implementation of the hardware and software elements.

Support during the design and development processes (RQ-3) and *different views on the system* *and available technologies (RQ-4):* The Interactive Story Engine allows to textually simulate the interaction within the environment. The views on the story scenario allow the team of experts to review the already defined components from different perspectives.

Evolvability of the story scenario (RQ-5) and *allow for reusable components (RQ-6):* The definition of the agent's items and easy addition of new components allows evolvability of the interactive story. The components and story blocks defined in one interactive story may be easily reused in another scenario by coping their properties.

Ease of use (RQ-7): The tool allows textual representation of the scenario, the user interface is based on text, choices and addition of pictures and can be easily used.

The usage of the *Tell me a Story!* tool was demonstrated in this chapter, in line with the design process that would follow more structured design of an interactive storytelling environment. However, the tool is a first prototype that applies only textual presentation of the story. Many improvements can be made in the *Tell me a Story!* tool:

Visualization. For interactive storyworlds that span virtual and physical worlds, it would be useful for a design environment to simulate the entire design setting. We imagine *Tell me a Story!* to be extended with a 3D visualization of the modeled physical world and simulation of the interaction features.

User friendly interface. We implemented simple lists and drop lists to choose the story elements and to define the relationships between the story elements. Drag and drop functions and graphical presentation of the different elements would allow easier manipulation of the story scenario (RQ-7).

Characterization. The main focus of the *Tell me a Story!* tool was on defining the story scenario. However, the creation of characters can be facilitated with introduction of a characterization tool. In Chapter 3, we referred to some tools and methods for characterization. Robotic agents and virtual animations have their own tools and methods to overcome the challenges of building such characters.

Reporting. The cost is an important issue for the project management. Reports that present estimation of the costs of a specific implemented environment would help the decisions in the team. The cost estimation and calculation can be made aside of the design tool. It is handy to add an estimate calculation of the cost for the system, depending on the involved components in the implementation.

Uni-directional code generation. We made a simple code generator that generates the skeleton for the controller from the provided story scenario in the *Tell me a Story!* tool. Parts from the code can be uploaded to the tool, to be added in the specific event handler. The manually added code will require additional tracking of the changes. Each implementation has specific platform and requires a specific code generator to be implemented. There is a lot of space left for research of how to complete the model to fit different implementation platforms. The components connected to event handlers need to be defined with all the necessary details.

Model checkers The validity of the defined model can be checked with formal methods, such as Linear Logic. Dang et al. (2010, 2013) present such methods which check if all the paths in an interactive story scenario lead to satisfactory endings of the goal of the game. Applying such Linear Logic models effectively determines whether the story plot contains error paths.

The full completion of such an extensive tool will require a team of developers. We did not have the resources to continue the development of the *Tell me a Story!* tool. For now, we have shown how the design process can be structured and facilitated with using the *Tell me a Story!* tool. We conclude that this tool is one of the required parts of the future development of a more complete design framework.

Part III

Experience

8

Understanding the User Experience

In this chapter we aim to provide a theoretical ground for the research of user experience of interactive stories in mixed reality environments. We give overview of the prominent frameworks and relevant research that concern the user experience in interactive storytelling systems. In the next two chapters, we present two empirical studies done in the ALICE installation that aim to research part of the contributing factors to the user experience.

8.1 Introduction

Interactive storytelling in mixed reality promises radically new modes of user experience, by offering users the opportunity to participate and co-narrate a story with physical presence and actions. The term *user experience* is associated with a wide variety of meanings, ranging from traditional usability to beauty, hedonic, affective or experiential aspects of technology use. The research related to understanding experience is focused on the interactions between people and technology and the experience that results. It includes all aspects of experiencing the technology: physical, sensual, cognitive, emotional, and aesthetic (Forlizzi and Battarbee, 2004, Hassenzahl and Tractinsky, 2006). Understanding experience is complex; Mandryk et al. (2006) state that evaluating entertainment technology is challenging because success is not defined in terms of productivity and performance, but in terms of *enjoyment* and *interaction*. User experience with entertainment technologies has been evaluated using a variety of concepts including *immersion*, *fun*, *presence*, *involvement*, *engagement*, *flow*, *play*, and *playability*.

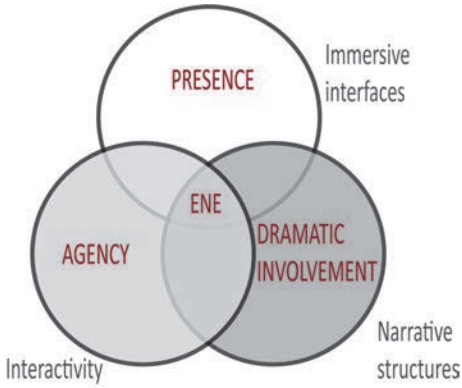


Figure 8.2.1: Dow's Embodied Narrative Engagement (ENE) Framework (Dow, 2008): the combination of three experiential pleasures: presence, agency, and dramatic involvement. The material properties (perceptually immersive interfaces, interactivity, and narrative structures) are features of the medium that can be manipulated by creators.

Cavazza et al. (2008) noted that user-centered research on interactive storytelling is not a well-established field. They discuss the evaluation issues of general system usability and the "entertainment value" or enjoyment of the experience delivered by interactive storytelling systems. Cavazza et al. (2008) conclude that "enjoyment is a highly complex experiential state with a variety of manifestations and numerous determinants attached to both the system delivering the experience and the person confronted with the system". To contribute to this issue, in this chapter we will give an overview of the most relevant research which attempts to describe and evaluate the user experience in interactive storytelling systems.

8.2 The Embodied Narrative Engagement Framework

Murray (1997) proposes three *aesthetic categories* for the analysis of interactive story experiences: immersion, agency, and transformation. *Immersion* is the feeling of being present in another place and feeling engaged in the action therein. *Agency* is the feeling of empowerment that comes from being able to take actions in the world whose effects relate to the player's intention. *Transformation* has at least three distinct meanings:

- *transformation as masquerade:* the game experience allows the player to transform themselves into someone else for the duration of the experience;
- *transformation as variety:* the game experience offers a multitude of variations on a theme; the player is able to exhaustively explore these variations and thus gain an understanding of the theme;

- *personal transformation:* the game experience takes the player on a journey of personal transformation. Transformation as masquerade and variety can be seen as means to effect personal transformation.

Dow (2008) defines a theoretical framework for embodied narrative engagement, based on the *aesthetic categories* defined by Murray (1997). The framework outlines *three experiential pleasures* of immersive and interactive stories (see Figure 8.2.1): presence, agency and dramatic involvement. *Presence* is described as the feeling of being within an environment; *agency* is the feeling of empowerment over the events; *dramatic involvement* is the feeling of being caught up in the plot and characters of a story. These experiential pleasures are relevant also for the user experience in interactive stories in mixed reality. In the following, we will give an overview of these recognized experiential pleasures and related research.

8.3 Presence

The term *presence* is often used synonymously with *immersion*, and is defined as the subjective experience of being in one place or environment, even when one is physically situated in another (Steuer, 1992). Immersion refers to the features or qualities of media technology that create sensory impact for the user. Numerous additional conceptualizations of presence have also been discussed; they can be divided into two types: *physical presence*, the sense of being physically located in a mediated space, and *social presence*, the sense of co-location and social interaction with a virtual or remote partner (IJsselsteijn et al., 2000, Lombard and Ditton, 1997). We will also give an overview of the notions of *dramatic* and *narrative presence* in Section 8.4, as relevant factors for the user experience in an interactive storyworld.

Lukas (2012) considers the user experience in "spatial stories" and the ways in which *designed spaces* provide an opportunity for immersion. The immersion and overall experience in such a story is based on *sensory* (sight, hearing, touch, taste, smell), *cognitive* ("How do you understand the world"), and *emotional levels* (searching for meaning, previous life experiences, empathy, what makes me feel good/bad). The story can also encourage associations between the space and the user's experiences: "I feel like I am in another world", "I feel that I am on a journey", "I feel I can change myself", etc.

Sheridan (1992), proposed three categories of determinants of presence: 1) the extent of *sensory information* presented to the participant, 2) *the level of control* the participant has over the various sensor and interface mechanisms and 3) the ability to *interact* with the virtual or remote environment and to affect a change within that environment. Witmer and Singer (1998), argue that presence is based on the interaction between sensory stimulation, environmental factors that encourage involvement and enable immersion, and internal tendencies to become involved. They distinguish four groups of factors that contribute to the sense of presence: *sensory factors*, *control factors*, *distraction factors* and *realism factors*:

Sensory factors refer to sensory modalities, the richness of the environment with multimodal sensory information and consistency of the multimodal information. The more complete and coherently all the senses are stimulated, the stronger the sense of presence will be (Sheridan, 1992). The information from different modalities should describe the same objective world (Held and Durlach, 1991); if there is a mismatch in the perceived messages through modalities, presence may diminish.

The *control factors* concern the degree and immediacy of control, and mode of control (Witmer and Singer, 1998). Individuals would experience greater sense of presence if they can anticipate the consequences of the actions, and if they can predict what will happen next.

The *distraction factors* refer to isolation from the outside environment and the willingness of the participant to have her attention towards the mediated environment.

Realism factors refer to scene realism, consistency of information with the objective world, the meaningfulness of the presented situation to the person that experiences the mediated environment (Witmer and Singer, 1998).

Most of the research on presence explores the tele-presence or presence in virtual reality environments. However, in mixed reality environments the experience happens in a real (physical) world. The perspective in mixed reality environment shifts from immaterial (virtual) to an environment with material objects and properties that engage all senses, also from passive to an active presence (Wagner et al., 2009). The participant takes action in a physical world and the control factors do differ from the ones in a virtual environment. These issues have to be taken into account during an evaluation of the user experience in a mixed reality environment.

8.4 Dramatic and Narrative Presence

The concept of *dramatic presence* refers to the experience of being present in a rich story world, with strong characters, aesthetic presentation, and long-term dramatic structure (Kelso et al., 1993). Dramatic presence can be viewed and further characterized as part of the broader concept of *narrative presence*, the sense of being in or part of a story. Narrative presence can be seen as an affective-cognitive construct that characterizes an audience's perceived relationship with a story (Rowe et al., 2007). Narrative presence is different from *physical* and *social presence*, as it refers to the perceived reality of the story and the experience of plausible cognitive and emotional reactions. Dow (2008) defines *dramatic involvement* as an experience when an individual is caught up in the characters and plot of the story; stating that the dramatic involvement that people feel is related with the personal interest for the story events and the specific content but also the underlaying narrative structure contributes to the desired effects.

Kelso et al. (1993) researched the *dramatic presence* in *live interactive drama*; they designed an experiment to investigate three basic questions: (1) how does it feel for an interactor to be immersed in a dramatic virtual world? (2) what is required of the actors in this world? (3) what are the requirements for the director to make an engaging interaction? They concluded that the experience of dramatic presence can be engrossing and powerful. The interactor, similarly to a viewer of non-interactive media, is willing to suspend his or her disbelief and to participate in the story. The interactors found interactive drama more powerful, since it causes immediate, personal emotions. The choices that have to be made during interactive experience, force the participant to confront herself into decision making, taking in consideration personal and moral issues; whereas in non-interactive mediums the audience experiences an empathy for other characters.

Swartjes and Theune (2009) investigated how to achieve a sense of *dramatic presence* by using *improvisational theatre (improv)* as a model for the experience. They setup an experiment in which the 'improv' actors attempt to evoke a feeling of dramatic presence for participants who have no 'improv' experience and to find out how the 'improv' actors might achieve it. Swartjes and Theune (2009) conclude that the experiment was enjoyable for the participants not only because they felt dramatically present, but also because they partook in the collaborative and creative process that generated the drama.

Glassner (2001) suggests three clauses of *"the story contract"*: 1) author is responsible for the psychological integrity of the main characters, 2) author is responsible for the sequencing and timing of major plot events; and 3) the audience must allow itself to be emotionally moved. Glassner also discusses some of the inherently contradictory needs of stories and games. Games have announced, objective, external and fixed *rules*, they are laid out in advance, and are explained to all the participants. In stories the rules of the world in which a story takes place need to be discovered, the rules are unknown on the beginning, and are subjective, internal and shifting. With allowing unguided exploration in a physical space, an additional burden for the design of the immersive environment is created. The introduction of physical movement and actuation often can be a threat for the safety of the participants. The design has to take into account all the necessary safety requirements, that will restrict the participants in their movements and actions.

Rowe et al. (2007) argue that *narrative* presence encompasses feelings of participation, embodiment, or disembodied observation in a story world; it is specifically associated with intrinsic processes that depend on the perception of a narrative. Rowe et al. (2007) propose several factors that may contribute to a user's sense of narrative presence grouped into *three groups of factors*: *narrative-centric*, *user-centric*, and *interpersonal factors*. In the following we summarize these factors, more detailed description is provided in (Rowe et al., 2007)

The *narrative-centric factors* are summarized in the following:

- *Consistency.* The elements of setting, plot and characters should remain consistent to maintain the narrative's believability and the expectation of the participants.
- *Plot coherence.* The plot should remain coherent as the events comprising the narrative's plot should occur in logical, causal order, or to be explainable through rational means;
- *Drama.* The interactive narrative should include setup, conflict, and resolution necessary

to produce an engaging, interesting plot. Providing an appealing, well-structured narrative potentially enhances an audience's interest and involvement.

- *Predictability.* The interactive features of characters, settings and events should occur and react with some level of predictability; the participants usually have expectation-based models of how a storyworld operates.

User-centric factors deal with the cognitive and affective elements of individual participants:

- *Affect.* Narratives that stimulate an audience's emotions may increase the sense of presence in the story, e.g. feeling of surprise, fear, anger or excitement may indicate strong involvement and suspend of disbelief in the unfolding narrative.
- *Motivation.* The user should be intrinsically motivated to keep participating, four types of motivation are classified: curiosity, challenge, control and fantasy.
- *Efficacy.* The efficacy refers to one's belief in her ability to perform; in an interactive experience efficacy concerns the abilities of the participant faced with challenges in the storyworld.
- *Control.* The participants in a storyworld become active by having control and freedom over the storyworld and events.

Interpersonal factors deal with the relationship between the user and key story elements:

- *Identification.* The participants in an interactive narrative would be more interested in the narrative if it appeals to their interest and will introduce opportunities for stronger emotional reactions than stories with little relevance for the audience.
- *Narrative Load.* Different narratives entail different requirements for suspension of disbelief, to understand the events and make sense of the plot; also the audiences have varying capacities for narrative load.
- *Character believability.* Characters can play important role in evoking emotional responses from an audience; their actions and appearance can encourage feelings of identification and socialization
- *Empathy.* Empathic feelings toward or from a character in a story are hypothesized to affect narrative presence.
- *Involvement.* Active involvement and attention toward plot advancement contribute to narrative presence.

All of these factors apply for the design of interactive stories in a mixed reality environments and have to be taken in consideration into the design process. For example, the narrative-centric factors imply design of consistent, coherent and well-structured narrative. The interpersonal factors (identification, narrative load, involvement) would go along with knowing the target group of participants that the storyworld is designed for, e.g. the age and background.

8.5 Agency

Agency is the feeling of empowerment that comes from being able to take actions in the world whose effects relate to the player's intention. The agency concept in media experience occurs when it provides means for user input and must result in some impact on the output - a feedback loop referred as interactivity (Dow, 2008). Without agency, the user is simply absorbing images or as in traditional theme park rides is moved by someone else's agency. The physical immersion in theme park rides can be uncanny experience, but the ride does not allow for any control over one's body movement. Interactivity usually is achieved by allowing manipulation of an interface from the user. The effect of the activity must relate to the participant's intention. There is no agency if the effects are not the same as the user intended.

Agency is defined by Murray (1997) as "the satisfying power to take meaningful action and see the results of our decisions and choices". Fencott (2003) looks at interactive digital storytelling as "the reconciliation of agency and narrative, stating: "on the one hand we have the 'confusion of consequence and consecution' and on the other hand we have participants needing to feel some sense of being in control - agency". Wardrip-Fruin et al. (2009) focus on agency in relation to the fictional worlds of games and interactive drama. They argue against the notation of agency as a "free will", but for considering agency as a phenomenon which occurs when the actions a player desires are among those she can take (and vice versa) as supported by an underlying computational model. Mateas (2001) gives a structural definition of agency, in line with the Neo-aristotelian model (explained in Section 3.1). "Players will experience agency when there is a balance between the material and formal constraints. When the actions motivated by the formal constraints (affordances) via dramatic probability in the plot are commensurate with the material constraints (affordances) made available from the levels of spectacle, pattern, language and thought, then players will experience agency. An imbalance results in a decrease in agency".

Taking actions in a mixed reality environment is different than in a virtual environment. In virtual environment one has to implement an avatar and a predefined control with a device, such as mouse or keyboard. In a physical space, an action may be walking around, which may have attached meaning in the context of the interactive narrative. However, the actions in an interactive storytelling environment should allow the story to move forward and to satisfy the intention of the participant. The design of the storyworld (i.e. characters, spatial settings) should implement enough guidance (formal constraints) which will make the participants aware about the more probable outcome in the storyworld.

8.6 The Motivational Appeal of Interactive Storytelling Experience

Roth et al. (2009) raise questions of how it feels to participate in an interactive story and why it should be enjoyable. Roth et al. (2009) conducted research on the 'past' generations of media entertainment such as literature, film, and video games, and generated conceptual insight for interactive storytelling. They proposed the experiential qualities of *curiosity*, *suspense*, *aesthetic pleasantness*, *self-enhancement*, and *optimal task engagement "flow"* as key elements of a theory of user experience in interactive storytelling. We will refer on these experiential qualities in the context of interactive storytelling in mixed reality:

Curiosity. In an interactive story, *curiosity* may occur in various modes, it may refer to the progress of the story, the action possibilities, artistic or formal issues related to the characters or the visualization provided by the director. Roth et al. (2009) enumerate several dimensions of curiosity in experiencing an interactive story: *pre-scripted story progress* ("What will happen next?"), *interactive story progress* ("What will happen if I go this way?"), *system response* ("How will the environment change if I touch this?") or *technological capacity* of the system ("How will the system perform this actuation?").

Suspense differs from curiosity in the sense that users experiencing suspense have a strong *interest in a specific outcome* of a story episode. Interactive storytelling applications can establish emotional involvement with characters and situations, and they may simultaneously generate a perception of personal challenge in users.

Aesthetic pleasantness is a positive evaluation that may relate to the *physical appearance* of characters, landscape imagery, or romantic episodes. It is likely that interactive storytelling systems can have profound aesthetic impact on their users. Roth et al. (2009) concludes, there are many routes that interactive storytelling systems may take to generate aesthetic pleasantness in their users. The users aesthetic perception may be facilitated through 'beautiful' arranged spaces, with creative plot development, character attributes, dialogue evolution. Aesthetic pleasantness is shaped also by *individual factors* (biography, sense of taste, social status), or *recognized citations* (e.g., a melody from a famous old movie being cited in a contemporary movie).

Self-enhancement. Interactive storytelling systems may facilitate identification with characters and/or provide experiences of competence and success, they are also likely to effect users' *self-esteem*, *self-perception* or *self-enhancement.* If users are directly involved in what happens in the story, they can attribute positive events to themselves (e.g., manage to overcome a puzzling situation).

Flow in interactive story may be achieved by a well structured interactive storytelling system that provide reasonable challenges as the participant in the story is making decisions and pushing a plot line forward.

8.7 Conclusions

We presented range of established theoretical frameworks that describe the factors that influence the user experience in interactive storytelling systems. We followed Murray's definitions of the *aesthetic categories* (immersion, agency, transformation) and Dow's theoretical framework with the *experiential pleasures* (presence, agency, dramatic involvement) of immersive and interactive stories. We presented different conceptualizations and approaches that attempt to give definition for the terms *presence, dramatic presence* and *agency*. Each definition enumerates the important determinants and factors. Most of the established frameworks concern virtual reality environments. We pointed out that mixed reality environment as a medium, would differ on how the factors of presence and agency are influenced, in comparison with virtual reality.

In the design of an interactive storyworlds there are many design decisions that affect the user experience. The designers of interactive storytelling environments would take into consideration the presented factors and experiential pleasures. Thus, it is necessary to empirically evaluate the various factors that are indicated to contribute and influence the user experience. Yet, there are not many research projects and necessary testbeds that allow empirical research of such user experiences. We used the ALICE installation as a testbed for investigating some of the factors that influence the user experience and contribute to richer user experience.

Taking the previously described *experiential pleasures*: presence, agency and dramatic involvement; we aimed to evaluate the effects in relation with parts of the ALICE installation. We refereed to three types of *presence*: spatial, social and narrative presence. Most relative for our research are *spatial* and *narrative or dramatic presence*. Four groups of factors were presented that contribute to the sense of spatial presence: *sensory factors, control factors, distraction factors* and *realism factors*. We also presented three groups of factors that influence the *narrative presence*: *narrative centric factors* (consistency, plot coherence, drama, predictability), *user-centric factors* (affect, motivation, efficacy, control) and *interpersonal factors* (identification, narrative load, character believability, empathy, involvement).

It is clear that we are not able to investigate all of the mentioned factors that influence the user experience in the ALICE installation. So far, there are not many research studies that have examined users' experiential qualities in specific interactive storytelling settings. Our attempt is to make the first step and to establish necessary empirical knowledge.

Taking into account the technologies and modalities that enrich the storytelling environment, we evaluated the influence of the sound design on the feelings of presence, agency and satisfaction. Moreover, we have to take in consideration the *user-centric* and *interpersonal factors* that influence the narrative presence. To do so, we investigated how the user's preknowledge of the narrative influences the user experience. The effects of interactivity on the user experience was investigated in a second study. The experimental settings and results are presented in the two following chapters.

9

On Sound Design and Users' Preknowledge of the Background Story

We use the first three stages from the ALICE installation, to explore the challenges in designing an interactive narrative in mixed reality and the factors that contribute to the user experience. We study the effects of *sound design* and *participant's preknowledge of the narrative* on the feelings of presence and the subjective evaluation of the experience. The study was carried out with 60 participants and the results showed that immersiveness (presence) is influenced by both factors. Furthermore, we discuss the user experience through observations and information gathered in interview sessions.

9.1 Introduction

In the previous chapter we gave full overview of the factors that influence the feelings of presence. We noticed that the immersion and the overall experience in a mediated storyworld is based on *sensory* and *cognitive levels*. The *modality* through which the information is presented affects how presence is experienced (Witmer and Singer, 1998). We presented a whole palette of modalities that influence the experience in a mediated storyworld, from which, we decided to empirically investigate the auditory mode. It is also known that presence should increase as

Parts of this chapter appear in Nakevska et al. (2014a) the situation presented becomes more meaningful to the person; meaningfulness is often related to many other factors, such as motivation to learn or perform and previous experience (Witmer and Singer, 1998). Since we create an environment which does not provide a "manual" to the participants of how they should behave or what to expect in the immersive environment. We wanted to investigate if their preknowledge of the story will help them to act more appropriately in order to go through the designed storyplot.

Sound design. In Chapter 4 we discussed the importance of sound and the developed techniques for producing audio that allows the audience to feel immersed. We described the types of sound that are used in the entertainment industry: speech, sound effects and music (Liljedahl, 2011). We used these techniques and sound types in the design of the ALICE installation. In Section 5.1 we described the redesigned stages and the implementation of sound design to enhance the immersivenss and interactivity of the environment. In this chapter we investigate how an enriched sound design with music and ambient sound effects will affect the user experience in the mixed reality environment of the ALICE installation.

Preknowledge of the background story. In the ALICE installation the participant takes the role of the character Alice and should experience a similar sequence of emotional and behavioural states as Alice did in the narrative. The participant should be intrinsically motivated to keep participating in this type of explorative experience. Bostan and Marsh (2010) points out that motivation to reach a goal is influenced by both personal factors (needs, motivations, and goals) and situational factors (opportunities and possible incentives provided by the environment). Interactive media such as games usually use pre-game stories to bridge the in-game stories, so the players can easily understand the game context and enjoy being immersed in game playing without the need to pick up a narrative on-the-fly. Disney and Eisner (1996) claim that the background story greatly increases the believability of a theme park attraction since every themed item has an explanation for its existence. The background story increases the participants' familiarity with the characters, context, and environment, and ultimately helps them quickly understand the designed story. This, in the end, facilitates the participant's enjoyment of the experience and also provides the participants with a strong motivation, since it enhances the psychological involvement with the characters and the role-playing. The story helps the participant orient in the conventions of the world and align their expectations with the logic of the mediated world.

Each participant has different preknowledge of the background story, they might have seen movies, played games, or visited attractions that are inspired by the narrative "Alice‘s adventures in Wonderland" Carroll (1865). We are interested in investigating the practical implications that are coming from different preknowledge of the background story and to which extent different preknowledge will affect the participants' experience.

9.2 Overview and hypothesis

A between-groups, two-by-two factor design was employed with the two factors being the sound design and the participants' preknowledge of the narrative. We expect that the enhanced sound design and richer preknowledge of the narrative to increase the feelings of spatial presence and the experience to be evaluated more positively.

In the remainder of the chapter, we present the experimental setup with the statistical results, interviewing data and discussion, resulting in several conclusions summarized in the last section.

9.3 Experiment

9.3.1 Method

We used Stage 1 to Stage 3 of the ALICE installation for this experiment, parts of them were already described in Chapter 5, the sound conditions are described in the following. For the sound condition we designed two different settings: (1) AMSS - having a soundscape that consists of ambient sound effects, music, and speech; (2) SS - does not include ambient sound effects and music, but does include speech. In the following, we describe how the soundscape was implemented in each of the stages.

Stage-1: "In the park". Stage 1 represents park environment, it was described in Section 5.2; here we refer only to the differences in the sound condition. The soundscape was different for the two sound conditions:

Ambient sound and music (AMSS): The ambient sound in *Stage-1* consists of nature ambience and singing birds combined with pleasant piano music. The positive and dreamy mood of the ambient sound is changed (into ambient sound featuring crows and dramatic piano music), in case the participant tries to enter the rabbit hole before being prompted to do so (by activating a sensor next to the rabbit hole). When the participant is expected to continue in the next stage, the volume is faded out for the ambient sound from *Stage-1*, while a "wind" sound starts from *Stage-2*. If the participant does not enter the second stage in three minutes, a "fantasy" piano sound is played from direction of *Stage-2*. Sounds in both stages are directional (determined by the position of the speakers), so the participant's orientation towards the next stage is supported by the spatial positioning of the sound.

Speech (SS): An ambient sound or music is not included. If the participant does not enter the "rabbit hole" after the rabbit runs in the scene she is invited with one of the pre-recorded samples: *"Come on, follow me!"*, *"In the left corner, follow me!"*, *"Okay, you are not going to find it!"*, *"Why are you just sitting there?"*. Each 3 minutes randomly one of these sounds is played, until the participant decides to go further.

Stage-2: "Down the Rabbit Hole". The second stage is the point where "the journey begins", and there is no possibility to go back to the pleasant and safe "park" environment. The design details of this stage were given in Section 5.3.

In this stage for the SS condition there is no sound, but only for the AMSS condition: soundscape is composed for each part of this ride, which match the position of the participant with the physical object and appropriate sound effect. The soundscape was designed as a mixture of

Figure 9.3.1: Stage-3: (a) VR small white door, (b) opening of the door and view on the garden, (c) on of the VR doors projected on one of the other four sides, (d) bottle "Drink me", cookie box "Eat me"

fantasy and mysterious music, and incorporates sound effects from the physical objects, such as electricity from the lighting or ticking clocks.

Stage-3: "Shrinking and Growing". The third stage is associated with personal space and the feeling of changing of the relative size between the participant and the environment. The design of Stage 3 similar as one described in Section 5.4, but it does not involve all the interactive features, since we used one of the earlier iterations.

After the participant enters the CAVE, her presence is detected by pressure sensors on the floor and the sliding door behind closes: she is trapped. The "Eat me" and "Drink me" props are depicted in Figure 9.3.1(d), featuring tilt sensor and an IR sensor respectivelly. When the participant eats or drinks the room gets bigger, which should create a feeling that she is getting smaller. If she does a second action (eat or drink) afterwards, the room becomes smaller, with the intended result that the participant feels bigger and also the door seems to be bigger.

The floor of the CAVE is covered with pressure sensors, so the position of the participant is known and the system can react to steps and position changes. If the participant approaches the door where she should be able to exit the room, the virtual door will open and a beautiful garden will be shown, see Figure 9.3.1 (b). If she goes away from there, the door will be closed, see Figure 9.3.1 (a). With this the environment shows to the participant where the exit is.

Similar to Stage 2, in the third stage there is no sound for the SS condition, only for the AMSS condition: Each activation of a pressure sensor on the CAVE floor is manifested as a cracking sound. The cracking sounds are different depending on the previously taken actions, if the participant is "big", the cracking sound of the floor is heavier, and vise versa, if "small" the cracking sounds are more short and light. The ambient sound is composed by fantasy music and the sound of water drops. Also the "water drop" sound has different echo depending on the relative size of the room (and the participant).

9.3.2 Procedure and Participants

The experiment was advertised as "an experience in a designed environment". It was not revealed it is an interactive or storytelling environment and the "Alice's Adventures in Wonderland" nar-

Table 9.3.1: Number of participants per condition

Pre-knowledge of the narrative	Sound AMSS	Sound SS
High (HPKN)	14	12
Low (LPKN)	7	16
Interuptions	5	1
Technical problems	3	2

rative was not mentioned.

Before the experience, the participants had to fill in a consent form (see Appendix B, in which, among the common statements, they confirm that are not afraid of heights or dark and closed spaces. They were introduced by the researcher with *Stage 1* and were instructed to "explore and have fun". Information about the consecutive spaces was not given. Each of the participants experienced Stage 1, 2, and 3 with just one of the sound conditions (AMSS or SS).

Immediately after the experience, the participants completed several questionnaires and were interviewed by the experimenter. The duration of each session was approximately 45-60 minutes, including briefing and instructions (5-7 min.), experience through the installation (15-30 min.), filling out the questionnaires (10-15 min.) and the closing interview (5-10 min.).

Sixty participants joined the study, from 18 to 39 years old (26 male, 37 female, mean age 25, SD = 4), of which twenty nine were in the AMSS condition and thirty one in the SS condition. All participants received an incentive of 10 euros for their participation.

9.3.3 Measurements

Presence. We used the MEC - Spatial Presence Questionnaire (Vorderer et al., 2004), which consists of several scales that measure different dimensions of spatial presence. This instrument assesses nine constructs associated with spatial presence, including traits (e.g., absorption and imagery skills) and spatial presence states (e.g., spatial situation model and possible actions). We included the most relevant spatial presence dimensions for our study: attention allocation, self location, possible actions, higher cognitive involvement, and suspension of disbelief. The items were adapted to refer to *story* as a mediated environment instead of "environment of presentation" in the original questionnaire. All the dimensions are represented by six items. As suggested, we used 5-point Likert scales ranging from 1 (*"I do not agree at all"*) to 5 (*"I fully agree"*).

Preknowledge of the background story. We did not want to influence the perception of the environment in relation to the intended design of the background story. So, we positioned the questionnaire regarding the participant's preknowledge of the narrative on the end. The participants were asked: *How familiar they are with the story "Alice's Adventures in Wonderland"; the characters and events and the character of Alice.* Also, whether they *have watched any movies, played* *games or have other experience inspired or related to the story "Alice's Adventures in Wonderland"*.

Subjective ratings. The participants were asked to evaluate the experience per stage and holistic (all stages). *"Please rate how did you feel per stage and during the whole experience"*, featuring: *bored, curious, dreamy, afraid, disoriented,* and *excited*. Each of them was rated on a 5-point Likert scale from 1 (*"Not at all"*) to 5(*"Very much"*) They were also asked to rate the setting: *"Please rate the mood of the setting per stage and during the whole experience. The setting was:"*; *pleasant, safe* and *coherent*.

The full questionnaire that was presented to the participant immediately after the experience, can be found in Appendix B.

Interview. In order to gain deeper insight in special unforeseen events that occurred during the experiment sessions and to record the participants' general opinions, a semi-structured interview was conducted with each of them. During the interview, the researcher also asked questions based on specific behaviour or actions of the participants that they observed during the experiment. Using a list of open questions as a structure, the participants were asked to share their experiences within the environment and also to think about possible improvements.

9.4 Results

Six participants withdrew from the experiment, and five participants were excluded from the data analysis because there were mistakes on the system side during their experimental sessions. From the participants who aborted the experiment on their own initiative, four were afraid to continue in *Stage 2* because it seemed too dark, and two did not discover the rest of the story since they did not explore in *Stage 1* to reveal how the experience might continue. From short interviews with the participants who aborted the experiment, we conclude that the experiment did not meet their expectations: they expected that it would be only one room based on their previous experience with research experiments. Taking these limitations aside, we analyzed the data from 49 participants as shown in the following:

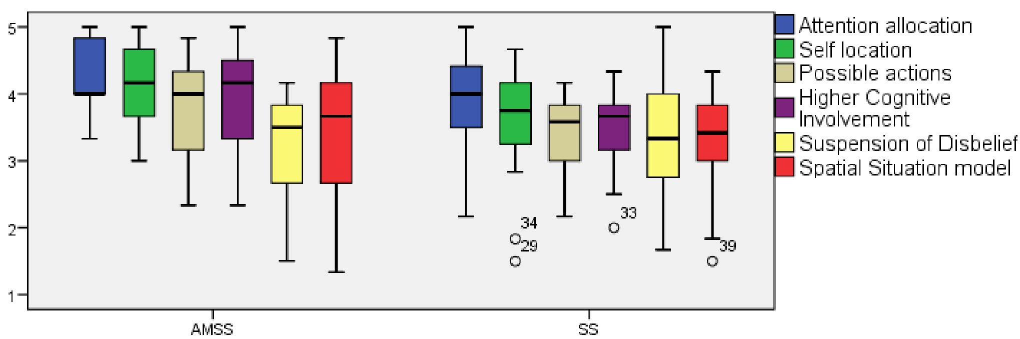


Figure 9.4.1: Presence indicators in the AMSS and SS sound conditions

Based on the data regarding the pre-knowledge of the background story we could divide two groups of participants: (a) participants that have high pre-knowledge of the background story (HPKS) and (b) participants that have low pre-knowledge of the background story (LPKS). The number of participants per conditions are presented in Table . 9.3.1

A two-way ANOVA of sound design conditions (AMSS, SS) and pre-knowledge of the story (HPKS, LPKS) on presence and subjective rating of the experience was conducted.

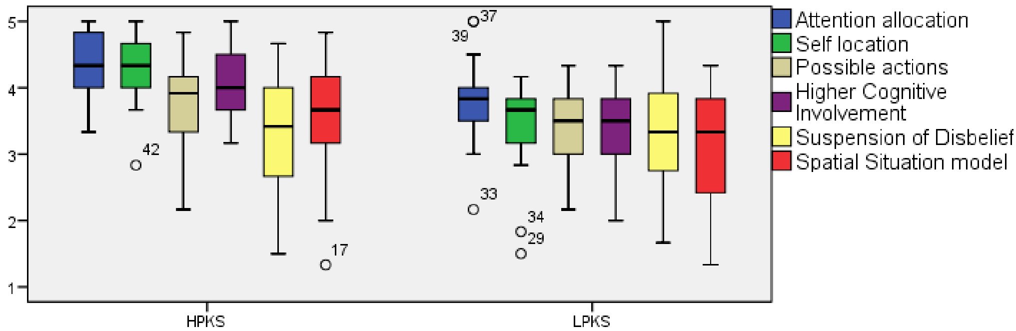


Figure 9.4.2: Presence indicators in the HPKS and LPKS variables

A significant main effect of the sound condition on *Self location* was found, $F(1, 45) = 4.59, p = 0.038$. *Self location* was rated higher for [Sound, AMSS] ($M = 4,04$) than for [Sound, SS] ($M = 3,67$). The main effect of *Attention allocation, Possible Actions, Higher Cognitive Involvement, Suspension of disbelief* and *Spatial Situation Model* was not significant.

A significant main effect of the preknowledge of the narrative was found on *Attention Allocation* $F(1, 45) = 10.98, p = 0.002$, on *Self location* $F(1, 45) = 20.24, p < 0.001$, and *Higher Cognitive Involvement* $F(1, 45) = 1.72, p = 0.001$. *Attention allocation* is higher for high ($M = 4.36$) than for low ($M = 3.78$) pre-knowledge of the story; *Self location* rated higher for high ($M = 4.25$) than for low ($M = 3.47$) pre-knowledge of the story; *Higher Cognitive Involvement* is higher for high ($M = 3.98$) than low ($M = 3.33$) pre-knowledge of the story.

The Sound x Preknowledge of the story interaction was significant for *Higher Cognitive Involvement* factor, though it did not qualify the main effects, $F(1, 45) = 4.55, p = 0.038$.

A significant main effect of the sound condition on the subjective rating of *Afraid (Stage-2)* and *Excited (Stage-3)* was found. The means for each of the ratings are displayed in Table 9.4.1.

A significant main effect of the pre-knowledge of the story was found on the subjective rating of *Bored (Stage-3), Curious (Stage-1), Dreamy (Stage-2) (Stage-3) (Holistic)* and *Disoriented (Stage-2) (Stage-3) (Holistic)*. The means for each of the ratings for the pre-knowledge of the story condition are displayed in Table 9.4.2.

Table 9.4.1: Subjective ratings for the sound conditions: AMSS and SS per stage and holistically(all stages)

Subjective rating	AMSS	SS	df	F
Bored - Stage 1	$M = 3.14$ $SD = 0.27$	$M = 3.00$ $SD = 2.23$	1, 45	0.16
Bored - Stage 2	$M = 1.21$ $SD = 0.15$	$M = 1.43$ $SD = 0.13$	1, 45	1.12
Bored - Stage 3	$M = 1.78$ $SD = 0.21$	$M = 1.77$ $SD = 0.17$	1, 45	0.003
Bored - Holistic	$M = 1.86$ $SD = 0.19$	$M = 1.83$ $SD = 0.62$	1, 45	0.01
Curious - Stage 1	$M = 3.57$ $SD = 0.23$	$M = 3.83$ $SD = 0.18$	1, 45	0.80
Curious - Stage 2	$M = 4.32$ $SD = 0.19$	$M = 4.41$ $SD = 0.16$	1, 45	0.14
Curious - Stage 3	$M = 4.36$ $SD = 0.19$	$M = 4.03$ $SD = 0.16$	1, 45	1.78
Curious - Holistic	$M = 4.25$ $SD = 0.17$	$M = 4.19$ $SD = 0.14$	1, 45	0.05
Dreamy - Stage 1	$M = 2.93$ $SD = 0.27$	$M = 2.44$ $SD = 0.22$	1, 45	1.97
Dreamy - Stage 2	$M = 3.29$ $SD = 0.29$	$M = 3.19$ $SD = 0.24$	1, 45	0.05
Dreamy - Stage 3	$M = 2.96$ $SD = 0.25$	$M = 2.66$ $SD = 0.21$	1, 45	0.81
Dreamy - Holistic	$M = 3.43$ $SD = 0.24$	$M = 2.95$ $SD = 0.19$	1, 45	2.28
Afraid - Stage 1	$M = 1.50$ $SD = 0.24$	$M = 1.78$ $SD = 0.20$	1, 45	0.44
Afraid - Stage 2	$M = 3.21$ $SD = 0.25$	$M = 2.17$ $SD = 0.21$	1, 45	9.76*
Afraid - Stage 3	$M = 1.93$ $SD = 0.20$	$M = 1.49$ $SD = 0.16$	1, 45	2.85
Afraid - Holistic	$M = 2.14$ $SD = 0.23$	$M = 1.81$ $SD = 0.19$	1, 45	1.20
Disoriented - Stage 1	$M = 1.93$ $SD = 0.29$	$M = 2.09$ $SD = 0.24$	1, 45	0.19
Disoriented - Stage 2	$M = 2.64$ $SD = 0.25$	$M = 2.04$ $SD = 0.21$	1, 45	3.34
Disoriented - Stage 3	$M = 2.39$ $SD = 0.26$	$M = 1.85$ $SD = 0.21$	1, 45	2.56
Disoriented - Holistic	$M = 3.23$ $SD = 0.24$	$M = 1.92$ $SD = 0.20$	1, 45	1.83
Excited - Stage 1	$M = 2.85$ $SD = 0.23$	$M = 2.85$ $SD = 0.23$	1, 45	0.01
Excited - Stage 2	$M = 4.46$ $SD = 0.19$	$M = 4.28$ $SD = 0.15$	1, 45	0.54
Excited - Stage 3	$M = 4.07$ $SD = 0.19$	$M = 3.55$ $SD = 0.16$	1, 45	4.28*
Excited - Holistic	$M = 3.92$ $SD = 0.19$	$M = 3.55$ $SD = 0.16$	1, 45	2.25

$* p < 0.05$

9.5 Interviewing Data and Discussion

The interviews were recorded with an audio recorder and transcribed separately; the explanations and interview transcripts were carefully analysed and grouped.

Based on the interview analysis we noticed a clear distinction in the answers between the participants who had rich and present preknowledge of the story and the ones who did not know the background story at all.

Participants who had good preknowledge of the story explained that in some actions they

Table 9.4.2: Subjective ratings for the high and low pre-knowledge of the story per stage and holistically(all stages)

Subjective rating	HPKS	LPKS	df	F
Bored - Stage 1	$M = 2.87$ $SD = 0.23$	$M = 3.27$ $SD = 0.27$	1, 45	1.23
Bored - Stage 2	$M = 1.42$ $SD = 0.13$	$M = 1.22$ $SD = 0.15$	1, 45	1.02
Bored - Stage 3	$M = 1.35$ $SD = 0.18$	$M = 2.21$ $SD = 0.20$	1, 45	9.87*
Bored - Holistic	$M = 1.63$ $SD = 0.17$	$M = 2.05$ $SD = 0.19$	1, 45	2.67
Curious - Stage 1	$M = 4.01$ $SD = 0.19$	$M = 3.39$ $SD = 0.22$	1, 45	4.47*
Curious - Stage 2	$M = 4.34$ $SD = 0.17$	$M = 4.39$ $SD = 0.19$	1, 45	0.03
Curious - Stage 3	$M = 4.35$ $SD = 0.16$	$M = 4.03$ $SD = 0.18$	1, 45	1.78
Curious - Holistic	$M = 4.42$ $SD = 0.15$	$M = 4.03$ $SD = 0.17$	1, 45	2.95
Dreamy - Stage 1	$M = 2.89$ $SD = 0.23$	$M = 2.47$ $SD = 0.26$	1, 45	1.45
Dreamy - Stage 2	$M = 3.64$ $SD = 0.25$	$M = 2.83$ $SD = 0.28$	1, 45	4.53*
Dreamy - Stage 3	$M = 3.24$ $SD = 0.22$	$M = 2.39$ $SD = 0.25$	1, 45	6.57*
Dreamy - Holistic	$M = 3.51$ $SD = 0.20$	$M = 2.87$ $SD = 0.24$	1, 45	4.19*
Afraid - Stage 1	$M = 1.88$ $SD = 0.20$	$M = 1.32$ $SD = 0.24$	1, 45	3.23
Afraid - Stage 2	$M = 2.39$ $SD = 0.22$	$M = 2.98$ $SD = 0.25$	1, 45	3.03
Afraid - Stage 3	$M = 1.49$ $SD = 0.17$	$M = 1.92$ $SD = 0.19$	1, 45	2.74
Afraid - Holistic	$M = 1.80$ $SD = 0.19$	$M = 2.15$ $SD = 0.23$	1, 45	1.33
Disoriented - Stage 1	$M = 1.93$ $SD = 0.25$	$M = 2.09$ $SD = 0.29$	1, 45	0.19
Disoriented - Stage 2	$M = 1.92$ $SD = 0.22$	$M = 2.77$ $SD = 0.25$	1, 45	6.69*
Disoriented - Stage 3	$M = 1.89$ $SD = 0.22$	$M = 2.35$ $SD = 0.22$	1, 45	1.78*
Disoriented - Holistic	$M = 1.93$ $SD = 0.25$	$M = 2.45$ $SD = 0.24$	1, 45	3.77*
Excited - Stage 1	$M = 2.97$ $SD = 0.19$	$M = 2.71$ $SD = 0.23$	1, 45	0.75
Excited - Stage 2	$M = 4.37$ $SD = 0.16$	$M = 4.37$ $SD = 0.18$	1, 45	0.00
Excited - Stage 3	$M = 4.05$ $SD = 0.16$	$M = 3.57$ $SD = 0.19$	1, 45	3.53
Excited - Holistic	$M = 3.83$ $SD = 0.16$	$M = 3.64$ $SD = 0.19$	1, 45	0.55

$*p < 0.05$

tried to remind themselves what Alice did in the movie and tried to replicate similar behavior:

P1: *"Because I know the story little bit and the movie also, it really interfered with your mind. You are thinking what happened in the movie what should I do. Especially in stage 3. I remembered that she did drink or eat, whatever and regretted it or something. So I was thinking should I do it that or maybe not."*

The preknowledge of the narrative was manifested in how motivated and exited they felt about the experience, which contributes to the immersion and the role-taking:

P26: *"And then I saw the rabbit and I thought: Alice in Wonderland! Where is the rabbit hole I* *want to go in there! "* P16: *"It was really really nice. I like the part with going down. It was really well done, and exciting. I was really like in the Alice story. "*

The participants who had low or no preknowledge of the background story, were less motivated by the experience. Although they liked the environment, they judged it as a *"weird"*, *"strange"* experience, or they stated they do not know what it means:

P8: *"It was very fun. Something different. For someone who does not know the storyline at all. It is very weird and confusing."*

P12: *"I like it very much. It is a lot different from what you expect. It was quite strange experience. It was not like life outside."*

P6: *"In the second stage is mystery but had not got it, I don't know what it mean, maybe it is just a room. I don't know what it mean."*

Nevertheless, participants with low pre-knowledge of the story also appreciated the experience:

P2: *"I like it when you go down. It is like a movie. You found something and you go down. It was cool. I don't know, I felt like a kid. And after that, it was the cookie part I was not sure if I have to eat the cookie. I like those too parts. Just feels like you are in the movie."*

P7: *"I thought it is pleasant environment. Like I was really in a story."*

Participants who had a better preknowledge of the background story were interested to see more of the story and the installation and to keep expanding the installation with additional characters and events from the story. Participants with no and low preknowledge proposed that more stimuli (e.g., interaction, lighting) and feedback (e.g., explicit speech) would help them to move through the story plot more smoothly.

The participants liked the experience, to describe it they used the words: *"surreal"*, *"interesting"*, *"quite fun"*, *"different"*, *"very nice experience"*, *"I enjoyed it so much."* P2: *"The impression was very positive. It was really nice. I really like it. It was too bad it ended."* P4: *"I was pleasantly surprised because I thought it will be only one room and then it turned to be whole new world. I was really amazed when it open up kind of."*

The participants addressed the quality of the arrangements and objects and the aesthetics of the details as possible improvements of the environment. Other general conclusion is that the environment could be enriched with more points of interaction.

Participants noticed that the experience in stages 1, 2, and 3 of the ALICE installation differs from other installations because it is an explicitly individual experience:

P16: *"I had time to think about my self. How I behave in a situation... That was quite interesting."*

P12: *"And the fact that you are completely alone and deserted in such an environment it makes it far more. You feel it more, I was really concentrated and noticed everything and right now in my heart, you feel everything. You are absorbing it but not sharing."*

We can speculate that being alone in several spaces of a mixed-reality installation, and having time and space to individually think about own behavior will give the participants room to self-reflect and to have a more intense experience. Furthermore, we will investigate whether this type of individual experience induces stronger emotions.

Most of the participants (84%) finished the experience in less than 15 minutes. However, there were also participants who needed about 30 minutes and more, and participants who aborted the experiment. Clearly, physicality of new mixed-reality storytelling environments introduces new types of safety issues. The designer has to consider all the regulations and precautions regarding the participants' safety.

9.6 Discussion and conclusions

The importance of sound in media like film and theater is well recognized. Sound is also well exploited in computer games and mixed reality games. Many research projects report on sound and audio's ability to create rich, strong and immersive experiences in mixed and virtual reality: Kurczak et al. (2011) evaluated ambient audio for location-based games and found that ambient audio increases the sense of immersion, although it reduces player performance in the game play. McCall et al. (2011) find out that sound in various forms contributed strongly to the sense of presence in the game world. This study showed that the enriched sound design has effect on *self location* in the storytelling environment, the items referred on being part of a story: *"I felt like I was part of a story", "It seemed as though my true location had shifted into a story"*, etc. We expected that the richer soundscape would also influence the other presence indicators, such as *suspension of disbelief* or *attention allocation*. Future research may further investigate these dimensions in relation to the properties of sound design. We did not investigate the separate types of sound (sound effects, music, speech), or variations of sound effects (wind, mystical, fantasy). We may speculate that some of the sounds were not pleasant (e.g. the wind sound that comes from the "rabbit hole") and may break the immersion and the suspension of disbelief. We may also notice that the questionnaire's items had average value that are above the middle value; which indicates that the physical environment is highly immersive even without any sound design. However, all of these assumption have to be evaluated in future studies.

Mixed reality is a novel medium, and there are still not developed grounds of how to approach the assessment of mixed reality environments and the mediated mixed reality experience. The assessment of the experience in the ALICE installation has to take into account the nature of a physical environment. The attention shifts from immaterial environments to environments with material objects and properties that engage all the senses, not only visual and auditory. The action in such environment shifts from passive presence to active, as the participants can move around and touch objects in the space. Future research should also reconsider the usage of the exising presence questionaires. One additional limitation of this study is the usage of subjective post hoc measures of experience such as MEC, where presence is measured based on the overall perception of the immersive environment consisting of three different physical spaces. Further studies would explore the user experience in a more detailed manner with focusing on smaller parts from the experience.

10 The Effects of Interactivity on User Experiences

We used Stage 3 "Eat me, Drink me" from our interactive installation ALICE, to investigate immersiveness and its contributing factors in a between-group design with a special focus on the effects of interactivity, and the feedback and feedforward stimuli of the environment on the users' experiences. The study was carried out with 41 participants and the results showed that immersiveness not necessarily depends on the modality of stimuli, but instead on their time-density.

10.1 Introduction

In Chapter 8 we presented full overview of the experiential pleasures that contribute to the user experience in interactive storytelling. We distinguish immersion (presence) and agency as important ones. To achieve agency in an interactive environment, the design calls for a set of affordances in which interactive and behavioral aspects of the interactive narrative environment influence the user and evoke certain expected behavior. Immersion is also affected by control factors, e.g. when acting in the environment, the consequences of that action should be apparent to the participant and to afford expected continuities.

A between subjects experiment was conducted to explore potential differences in sense of

Parts of this chapter appear in Nakevska et al. (2014b) presence, agency and satisfaction with different levels of interactivity. The independent variable was the interaction environment, with three levels: (a) Interactive responsive environment, (b) Non-interactive pre-programmed environment and (c) Non-interactive pre-programmed environment with minimum stimuli. The hypothesis was that the interactive setting should lead to higher levels of presence, agency and satisfaction. Further, we present the experimental setup and results regarding the relation between these variables of interactivity, presence and agency, resulting in several conclusions in the last paragraph.

10.2 Experiment

10.2.1 Procedure and participants

The participants were invited to take part of the "Alice's Adventures in Wonderland" and they were led into the room with the instruction to "have fun". It was not mentioned to the participants that it is interactive environment, or how and when they should find the way out from the VR room. They experienced one of the following interaction modes:

- **Interactive environment (IE):** The environment used all the available interaction features of the *"Eat me, drink me"* stage. The interactive setting was designed to give range of feedback and feedforward messages from the story characters. The feedback is implicit and depends on the actions of the user in the physical environment (walk, stands, drinks, takes cookie). For example, the steps of the participants are coupled with sound design simulating cracking floor; a narrator voice gives feedback on the behavior of the participant over longer time (by observing if she walks or stands in the environment). An explicit feedback is given by a doorknob, if the participant does not find the exit, after ten minutes, the doorknob points out which actions can be taken in order to finish the intended story plot.
  The full interaction design was described in Section 5.4 in Chapter 5.

- **Non-interactive environment (NIE):** A pre-programmed scenario (that uses 10 from the features) of the narrative is played without taking in consideration the behavior of the user.

- **Non-interactive with minimum stimuli (NIMS):** A pre-programmed scenario (that uses 4 features) of the narrative is played without taking in consideration the behavior of the user.

Forty-one participants joined the study, all university students from 18 to 33 years old (13 female, 28 male, mean age 23 with a standard deviation of 3). None of the participants had previous experience with the ALICE installation. By random selection the participants experienced one of the settings. Twelve participants joined the IE setting, sixteen joined the NIE and thirteen the NIMS setting. After the experience in the room, the visitors answered a questionnaire. All experimental sessions took less than 20 minutes including the experience about 4 minutes and the survey about 15 minutes.

10.2.2 Measurements

Presence. Participants were administered with the ITC-Sense of Presence Inventory (ITC-SOPI) to evaluate their levels of physical presence (Lessiter et al., 2001). The ITC-SOPI is a validated 44-item self-report questionnaire that was used in this study to measure how physically present and involved the users feel in the storytelling environment through four factors: spatial presence, engagement, ecological validity and negative effects.

Agency. We measured the subjectively perceived agency based on the perceived proficiency, the perceived responsiveness and technical aspects of the environment and how much the participants are aware of their influence on the events in the environment. The following items were created: *"I felt proficient in my actions with the environment during the experience"*, *"I was aware of my influence on control mechanisms in the environment"*, *"I felt that the environment was responsive to my behaviors"*. Since, agency is achieved when the actions of the user are causing the intended effect on the mediated world, we added items to check if the user's intention and the hints from the environment match. *"I knew what actions I should take to do to go out"*, *"I knew what I should do because the environment gave me a hint"*, *"The physical objects were obvious hint for interaction"*.

Satisfaction. We also measured how much the participants appreciated the experience. They were asked to rate the experience on several scales: *"The experience was: terrible, okay, good, great, best thing of entertainment experiences, best thing in my life"*, *"This is one of the best mediated experiences I have ever had"*, *"I have really enjoyed myself during this experience"*. And to choose on a 5-points Likert scale between: *"Very dissatisfied"* - *"Very satisfied"* and *"Terrible"* - *"Delighted"*.

Behavioral measures. We observed the users' behavior via video records from the surveillance system. The actions of the users recognized by the sensing mechanisms (pressure sensors, IR and tilt sensors) were recorded in a text file. We noted the actions that participants performed: walks around, touches objects or walls, eats, drinks, takes the key; and the emotional reactions such as smiling, laughing and verbal communication. The distinction of more complex reactions like confusion, frustration and satisfaction was based on the verbal reactions and body language.

10.3 Results

Figure 10.3.1 illustrates the means of the factors generated by the ITC-SOPI questionnaire (Lessiter et al., 2001), the agency and satisfaction questionnaires. Differences between the means for the three conditions for presence, engagement, naturalness, negative effect and satisfaction were examined for significance using a one-way ANOVA for independent groups design. The results

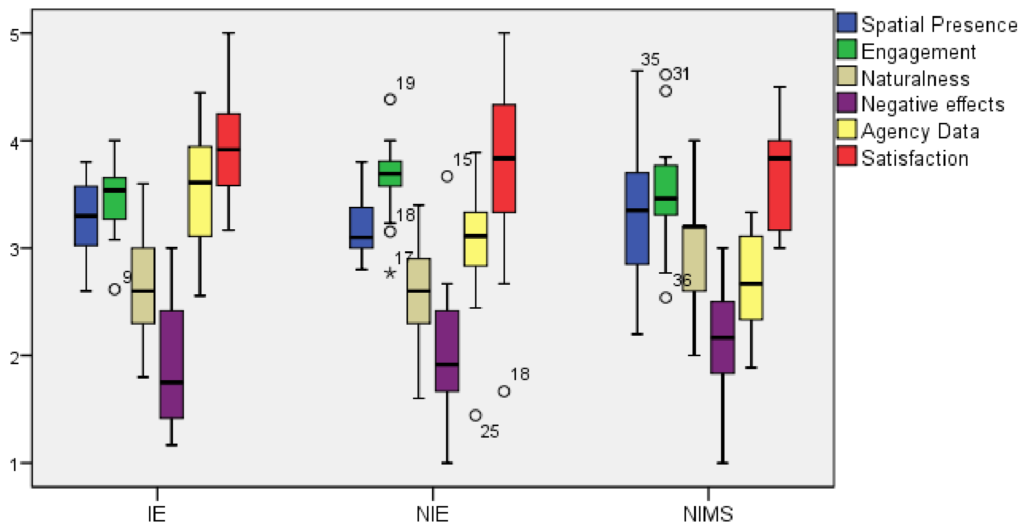


Figure 10.3.1: Dimensions of the presence(spatial presence, engagement, narutalness, negative effects), agency and satisfaction by treatment conditions: IE, NIE and NIMS

showed no significant differences between the three conditions for presence, engagement, naturalness, negative effect and satisfaction.

A one-way between subjects ANOVA was conducted to compare the effect on agency for IE, NIE and NIMS conditions. There was a significant effect on agency for the three conditions [$F(2, 38) = 8.209$, $p = 0.001$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for the IE condition ($M = 3.56$, $SD = 0.54$) was significantly different than the NIE condition ($M = 3.02$, $SD = 0.54$) and the NIMS condition ($M = 2.71$, $SD = 0.49$). The NIE condition did not significantly differ from NIMS condition.

Taking the data from the sensing mechanisms, we counted the number of actions that were triggered by the users. We compared the number of actions by the participants in each settings for the IE, NIE and NIMS conditions with one-way ANOVA. There was a significant difference for the three conditions [$F(2, 25) = 6.237$, $p = 0.006$]. Post hoc comparisons using the Tukey HSD test showed that the mean score for the IE condition ($M = 5.08$, $SD = 2.46$) was significantly different than the NIE condition ($M = 9.06$, $SD = 4.14$). The NIE condition is significantly different from the NIMS condition ($M = 4.66$, $SD = 3.44$). However, the number of actions from the participants in the IE condition does not differ significantly from the NIMS condition.

10.4 Discussion and Conclusions

In the interactive setting (IE) subjects had slightly different experience depending on the triggered stimuli and the actual context. Not everyone would reveal all of the events from the narrative, e.g. the virtual garden was visible only if the participant approached the small VR door and had the key. The order in which they would discover the events or the pace in which the story would be played differed for different participants. The events from the story were context related and they would trigger only if the person was at the right place on a right time.

The results showed that the interaction types did not influence the feelings of presence and the satisfaction from the experience. We originally expected that the presence factors of the interactive environment will be significantly higher than that of NIE and NIMS environment. We assume that the CAVE as a strongly immersive environment, contributes for high feelings of presence even when the environment is not responsive to the actions of the user.

Through observation of the actions of the users and by quantifying the number of actions we noticed differences in the users' behavior. The participants that were immersed in a not responsive environment(NIE) were more active and tried out more interaction possibilities (touch, walk, look around). The participants who experienced minimum stimuli in a non-interactive environment (NIMS) did not performed as many actions, instead they would rather stand and look around. The participants in the non-interactive environment (NIE) more often showed confusion and frustration, while the participants in the interactive environment (IE) seemed satisfied every time they discovered an interaction asset. The stimuli provided from the environment evoke different behavior and with that also a different personal user experiences.

In this chapter, we investigated the user interaction and the overall user experience. The study contributes to our knowledge about the design of interactive and mixed reality spaces, and how the responsiveness and the amount of stimuli induce or bias behavior and experiences. The interaction mode modulates the behavior of the participants, and their user experience. We have to point out that results obtained with the different settings over short durations of time have to be taken with precaution since its effects may vary over longer time periods. where presence and engagement are measured based on the overall perception of the immersive environment. Further studies would explore the user experience in an enriched interactive setting that implements more challenging scenario of the interactive narrative.

11
Conclusions and future work

This dissertation has explored interactive stories in mixed reality environments in a conceptual, tangible and empirical way. It offers an empirical, practice-based view on the design challenges, the design process and the user experience that will emerge. In this chapter we summarize our main contributions, give the answers to research questions, reflect on the limitations of our system and set the directions for future work.

11.1 Contributions

This thesis offers theoretical and practical explorations in the field of interactive storytelling in mixed reality: a theoretical and technical state of the art overview; a design artifact - the immersive and interactive installation ALICE; and a design tool that facilitates and supports an iterative design process. Moreover, it contributes with a literature review about understanding the user experience and provides the empirical evidence that expands our knowledge about the factors that influence the user experience in immersive and interactive stories. The research outcomes can be grouped in several major contributions of this thesis:

Theoretical and Technical Overview of Mixed Reality for Interactive Storytelling

We gave an overview of the creative opportunities that come from using mixed reality as a powerful medium for creation of interactive storyworlds, which allows the real and virtual worlds to function together as a new interactive medium. A state of the art overview of the available technologies and modalities was provided, which can serve as a guide to the future designers of immersive storyworlds.

In addition, a theoretical overview of the prominent narrative theories was presented, and we identified the fundamental concepts necessary for practical implementations of interactive stories. The core narrative elements (characters, settings, events and actions) and their spatial and temporal relations were defined. Finally, we reviewed the prominent strategies and approaches for creation of interactive stories.

The Design and Implementation of the ALICE Installation

Technically, the ALICE installation achieved what few other research and entertainment projects have accomplished: we managed to combine physical actuation, physical sensing mechanisms and virtual and mixed reality displays and characters, throughout several physical spaces. The explorations in the ALICE installation shed light on a range of architectural, interaction and content issues that will be relevant to any experience that immerse a participant in a mixed physical/virtual space. We made the first steps towards understanding the computational mechanisms for creation of context-aware interactive stories.

The design of complex interactive storytelling scenarios in mixed reality environments imposes new design challenges on the designer. The interaction mechanisms for physically interactive environments differ significantly, as they do not provide a set of interface elements but the participant's behavior is recognized as an interaction input. The iteration cycles in building the ALICE project show part of the possible approaches and solutions in achieving certain user experience.

Identifying the Design Challenges

The design of immersive and interactive stories poses new design challenges on the designer. Most of them were encountered in the practical work while redesigning the ALICE installation and were detected in the theoretical and state of the art overview. Three levels of design challenges were identified: 1) technology, 2) story, and 3) user related design challenges.

The analysis of the low-level *technology related design challenges* was done by defining the key material properties of technologies and modalities that can be integrated in the immersive interfaces of interactive storyworlds. These involve the usage of sensing mechanisms that are used in a physically interactive environment, actuation technologies and modalities that can convey a story in a physical space, and an implementation of a distributed context-aware system.

A top-down analysis was performed in order to identify the set of elements, properties and spatial and temporal relations that contribute to the *creation of a coherent story*. The design challenges on the story level refer to the design of story elements and structuring the story plot.

The *user related challenges* are strongly related to *interaction design*. Designers need to create user interfaces for an autonomous storytelling system which allow for intuitive interaction, and satisfies the participant to feel she controls or influences the development of the story. Immersive and interactive stories do not provide a set of interface elements that give control over a set of functions, but the sum of all the elements are perceived as one coherent story. However, already subtle flaws in the design can destroy this perception and can lead to negative effect on the interaction, potentially leading to frustration and the loss of the necessary suspension of disbelief. The challenge is to create interactive and immersive stories which benefit from the immersive and interactive properties of mixed reality environments, while taking into account the limitations of currently available technology and the limitations that come from the users' expectation, motivation and preknowledge. The challenge for the designer is to find an interface metaphor that will allow interaction within the story context.

The Design Tool - *Tell me a Story!*

This thesis also contributes with a discussion of the authoring process for interactive stories in mixed reality. The practical research on the ALICE project, gave us a rare opportunity to observe the design and development process and the work of diverse design teams. We gave overview of the complex design team, their roles and the requirements for building a design tool.

The design challenges have been analyzed at high abstraction level (creation of a coherent story) to low-level implementation of context-aware systems. The creation of coherent story has to take into account the maintaining of the narrative plot, while allowing for interactivity. *Tell me a Story!* is a design tool that implements strong story authoring approach, supports the creation of a complex story plan that is based on sequential and concurrent story blocks. Novel is the incorporation of the various modalities, actuation and sensing technologies for creation of mixed reality storyworlds. It supports a structured iterative design process which guides the design team. The design tool helps the design process all the way from conceptual definition of the story elements to realization of a control software. The usage of the tool was demonstrated on a case study, where all the phases of the design process were separately explained.

Theoretical and Empirical Argument about the User Experience

This thesis provides a theoretical overview of the established frameworks that describe the factors that influence the user experience in interactive storytelling systems. Mixed reality environments can use rich palette of technologies and modalities to engage all the senses and to elicit rich experiences for the users. The evaluation of such entertainment experiences is complex, since it asks for understanding the various contributing aspects of the overall experience. We contribute to this issue with a full literature overview of the observed contributing aspects in interactive storytelling, and we discuss the specifics of mixed reality.

The empirical data collected in two studies in the ALICE project suggests that the mixed reality environments induces a strong sense of presence, creating a highly immersive experience for the users. In the first study, we investigated the immersiveness factors and the overall experience. The results showed that the enriched sound design has effect on self location in the storytelling environment, while participants' preknowledge of the backstory has significant effect on attention allocation, self location and higher cognitive involvement presence indicators. Within interviewing sessions with the participants we heard the opinions of 60 participants that experienced the first three stages from the ALICE project. Most of the participants expressed a high appreciation of their experience in the ALICE installation. The second study explored the effects of different interaction modes on the feelings of presence, agency and satisfaction. We noticed that different interaction modes influence the behavior of the participant, and have an effect on the feelings of agency.

11.2 Limitations and Future Work

There are many open threads of work that can bring benefit to the design of immersive and interactive stories. In the following we highlight some further possible directions for future work that we have already started investigating.

Future Interactive Stories in Mixed Reality Environments

The experience of designing and creating the ALICE installation revealed number of possible research directions to explore. The challenges for mixed reality immersive and interactive stories include physical sensing (e.g. speech and gesture recognition), character design and physical/virtual interaction. The design process of the ALICE installation raises many questions and possibilities for future work on specific implementation details and design methodologies.

There are many research projects which use projection based methods to allow for different immersive setups in a home (Jones et al., 2014). We researched *location based* entertainment environments. This brings many creative opportunities for creating immersive storyworlds, but also brings many limitations as the user has to travel to the specific location in order to experience the interactive environment. Such environment has to provide *timed experience*, as each participant has to finish in a specific time. This constrain and the aim to implement free to explore interactive environment are contradictory. Our exploration showed that the environment has to provide enough feedback and feedforward mechanisms that would lead the participant through the interactive experience in a given time frame. We explored a part of the possible design solutions in the "Eat me, drink me" stage. The addition of feedback and feedforward mechanisms proved to be sufficient for that specific stage. Other approaches may be explored in different story context, such as ride through an interactive storyworld (Ellwood, 1998).

Physical sensing mechanisms impose an additional burden on the implementation of interaction features. Most of the limitations in the implementation of context aware systems in a physical world result from the *sensing technology*. In the ALICE installation we used a limited sensing technology that has the capacity for detection of only simple actions. Limited input from the environment restricts the interaction possibilities; some actions may be misinterpreted or not detected at all. For instance, we did not use vision sensing technology; adding such sensing mechanisms may provide valuable information about what is happening in the physical space. The ALICE project had not enough resources to explore this, since more advanced sensor additions require additional resources and expertise.

The *physical space* of the immersive environment may limit the extent of the mediated storyworld. In the ALICE installation the stages were built in succession, which limited decision choices when physically moving through the installation. Implementing the branching structure of the physical environment, with choices of more physical spaces, would be costly, but worthy direction to explore.

The system cannot always fully understand what the participant is doing in the environment. The *content* of the story should be build around actions that can be easilly understood, or may logically overcome the misunderstandings of the actions of the participants. It is a challenge to design appropriate *interaction mechanisms* that will move the story in the desired direction. Novel and implicit interaction features of physical environments may not be perceived by the participants as the designer has intended. Since there are no predefined interaction interfaces, the sensing mechanisms and interaction interfaces are not disclosed to the participants in front. The mismatch in the expectations of the participant from a certain action in the environment and its outcomes, would have have a negative effect on the suspension of disbelief and the feelings of presence and agency. Thus, the experience needs to be considered and carefully designed to create an effective interactive story. Well-designed narrative and interaction mechanisms may support the illusion of the mediated world.

The creative possibilities in the design of immersive environments are indeed rich. Yet, hurdles, such as complexity and cost, stay on the way for this form of entertainment to become widely utilized by the creative community, or to be enjoyed by the public. Having in mind the complexity and the costs in creating immersive and multimodal experiences in big physical spaces, we may expect that future realizations of such interactive environments will come from commercial sites, such as theme parks and location based entertainment.

Future Design tools

In order to support the design and development process, we contributed with a creation of the design tool *Tell me a Story!* Many improvements remain for the future development of this or similar design tools. A more complete design framework would fulfill a variety of functions that would help to conceptualize, visualize, analyze, explain and build. As we provided a pioneering set of requirements and a textually based tool, we expect that a future design framework will be expanding. There are many tools that are used in other fields, as robotics or virtual reality modeling, that can be borrowed and integrated into the future set of tools that would support the creation of interactive stories.

The designed physical space, often limits the user experience that can be provided. Therefore it is important at early stage to have clear idea about what is going to be built. The main goal of the tools that help this issue is to allow for pre-visualization of the storyworld and with that to enable the design team to communicate and develop the ideas. Mixed reality spans in virtual and physical worlds, thus it would be useful the design environment to simulate the entire design setting. For instance, virtual reality three-dimensional models would give an impression of the physical environment, which will help the designers to see and experience the storyworld before construction is started. In Section 7.6 we gave a list of possible improvements that can be made in the *Tell me a Story!* tool.

This project aimed to research mixed reality environments that would provide for *all the senses*. Such ambition brings many creative possibilities, but also many challenges on to way to achieving it. The future design tools that aim to support this ambition, will have to follow the expanding palette of technologies and to build upon it.

Empirical Research

The studies conducted in the ALICE project offer insights into how different types of interactivity, sound design and the participant's preknowledge of the story influence the overall user experience. In order to more completely understand the user experience in interactive storytelling installations, many other factors can be researched and investigated, such as narrative-centric and user-centric factors that influence the narrative presence. In Chapter 8 we reviewed the most prominent theoretical frameworks that define the main factors that influence the user experience in interactive storytelling systems. Each of the factors, can be investigated in separately controlled settings.

We noticed that the experience in the ALICE installation was very much appreciated and positively evaluated by the participants. We see a great potential in this type of interactive entertainment, and we wish to see more materialized interactive stories in mixed reality as a possible bridge to the vision of future interactive storytelling entertainment system.

Part IV

Appendix

A
Design tool

In this appendix are added materials that will give better impression of how the design tool *Tell me a Story!* looks:

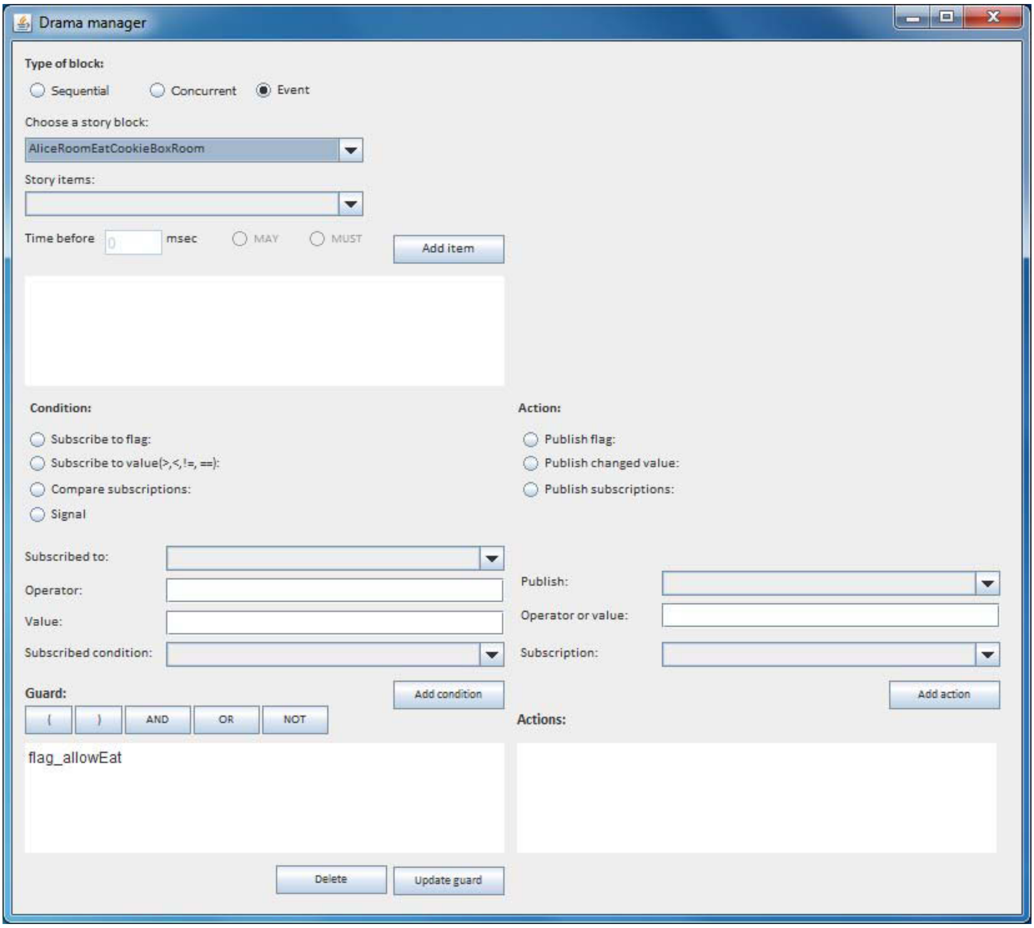


Figure A.0.1: Drama manager

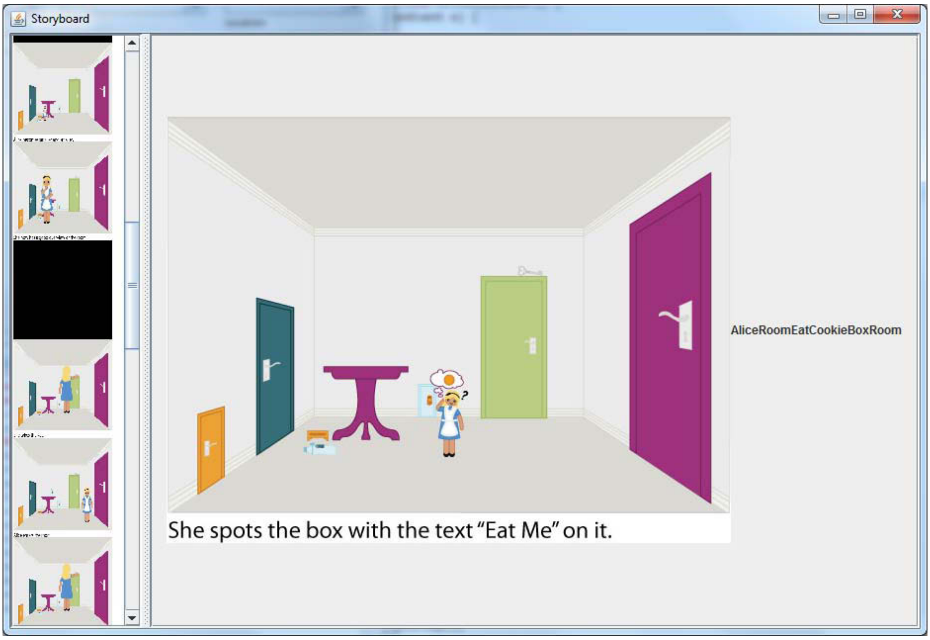


Figure A.0.2: Generated Storyboard from the *Tell me a Story!* tool

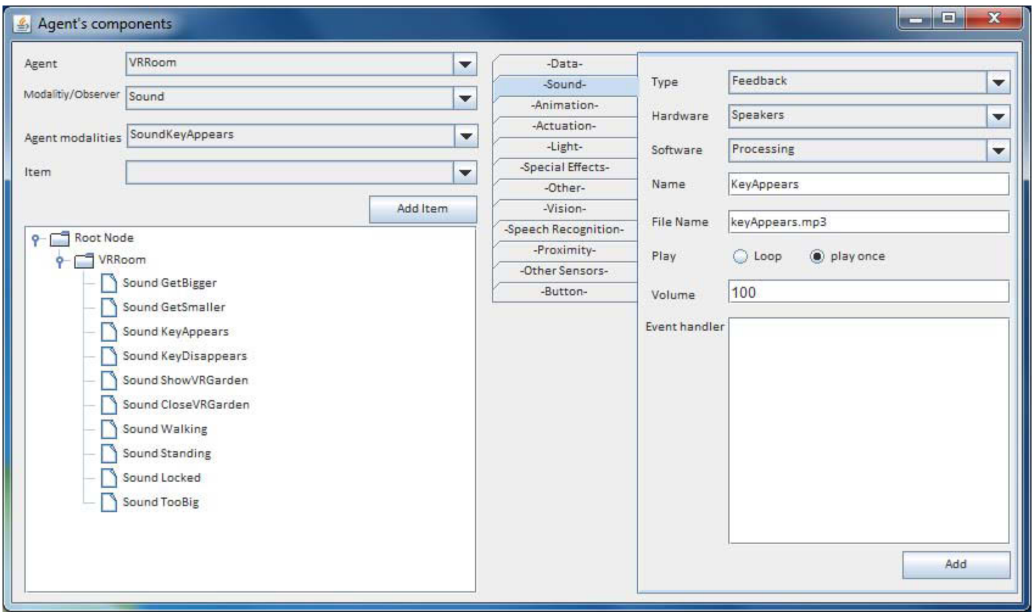


Figure A.0.3: Definition of the hardware and software components per agent and modality

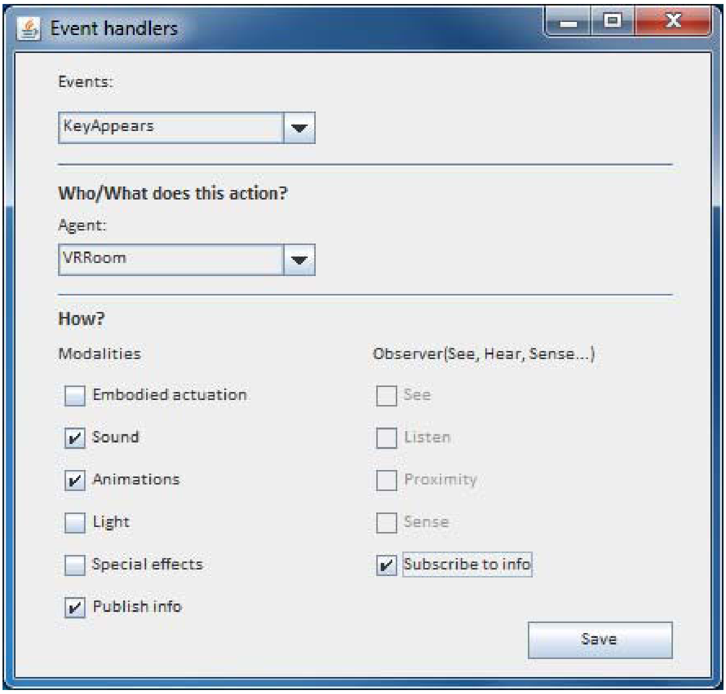


Figure A.0.4: Modalities and observers that handle each event

B
Experiment forms

These forms are used in the empirical study described in Chapter 9. A consent form presented to the participants before the experience:

Please read and complete this form carefully. If you are willing to participate in this study, check the appropriate responses and sign and date the declaration at the end. If you do not understand anything and would like more information, please ask.

You will be asked to leave all the electronic devices on a safe place before entering the designed environment and you will get them back on the end. We inform you that the offered food in the environment can be consumed. The research will involve experience through a designed environment, a digital survey and an interview. The experience through the environment will be recorded on a video surveillance system, and the interview will be audio taped. The total experience will take about 45 minutes. Please check the box if you agree:

1. I have had the research satisfactorily explained to me in written form by the researcher.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason.

3. I confirm that I don't have fear from heights.

4. I confirm that I don't have fear from closed and dark spaces.

5. I agree to take part in the above study.

6. I agree to the interview being audio recorded.

7. I agree to the experience through the installation being video recorded.

8. I agree to the use of data from the survey and anonymised quotes in publications.

Questionnaires that were fulfilled immediately after the experience:

Welcome! Please fill in this survey regarding the experience you just had. There are no correct answers, therefore please respond with your own opinion.
Please write your contact email in the box below to begin with the study: ________

Please answer the questions regarding the experience you just had:

(1) I do not agree at all (2) (3) I somewhat agree (4) (5) I fully agree

I devoted my whole attention to the environment.
I concentrated on the environment.
My attention was claimed by the environment.
The environment captured my senses.
I dedicated myself completely to the environment.
My perception focused on the environment almost automatically.

I felt like I was a part of a story.
I felt like I was actually there in a story.
I felt like the objects from a story surrounded me.
It was as though my true location had shifted into a story.
I felt as though I was physically present in a story.
It seemed as though I actually took part in a story.
I had the impression that I could act in a story.
I had the impression that I could be active in a story.
I felt like I could move around among the objects in a story.
The objects in the environment gave me the feeling that I could do things with them.
It seemed to me that I could have some effect on things in the story, as I do in real life.
It seemed to me that I could do whatever I wanted in the story.

I thought most about things having to do with the environment.
I thought intensely about the meaning of the environment.
I thoroughly considered what the things in the environment had to do with one another.
The environment activated my thinking.
I thought about whether the environment presentation could be of use to me.
I thought about just how much I know about the things in the environment.

I concentrated on whether there were any inconsistencies in the environment.
I didn't really pay attention to the existence of errors or inconsistencies in the environment.
I directed my attention to possible errors or contradictions in the environment.
I took a critical viewpoint of the environment.

It was important for me to check whether inconsistencies were present in the environment.
It was not important for me whether the environment contained errors or contradictions.

I was aware of my influence on control mechanisms in the environment.
The technical aspects of the environment were distractive.
I experienced delays between my actions and their outcomes.
I knew what actions I should take to do to go out.
I could relate my actions with the events that are happening around me.
I could concentrate on what is happening in the environment rather than the mechanisms behind them.

We will refer to the spaces you were in as:
Stage 1 - The park environment where you entered on the beginning.
Stage 2 - The space with many books and lights on shelves while you moved down.
Stage 3 - The projected room with many doors with a bottle and a cookie box/

How many minutes the experience lasted in Stage 1: ________
How many minutes the experience lasted in Stage 2: ________
How many minutes the experience lasted in Stage 3: ________

Please rate how you felt per stage and during the whole experience:

(1) Not at all *(2)* *(3) Somewhat* *(4)* *(5) Very much*

Bored-Stage 1
Bored-Stage 2
Bored-Stage 3
Bored-Holistic (all stages)
Curious-Stage 1
Curious-Stage 2
Curious-Stage 3
Curious-Holistic (all stages)
Dreamy-Stage 1
Dreamy-Stage 2
Dreamy-Stage 3
Dreamy-Holistic (all stages)
Afraid-Stage 1
Afraid-Stage 2
Afraid-Stage 3
Afraid-Holistic (all stages)
Disoriented-Stage 1

Disoriented-Stage 2
Disoriented-Stage 3
Disoriented-Holistic (all stages)
Excited-Stage 1
Excited-Stage 2
Excited-Stage 3
Excited-Holistic (all stages)

Please rate the mood of the setting per stage and during the whole experience. The setting was:

(1) Not at all	*(2)*	*(3) Somewhat*	*(4)*	*(5) Very much*

Pleasant-Stage 1
Pleasant-Stage 2
Pleasant-Stage 3
Pleasant-Holistic (all stages)
Safe-Stage 1
Safe-Stage 2
Safe-Stage 3
Safe-Holistic (all stages)
Coherent-Stage 1
Coherent-Stage 2
Coherent-Stage 3
Coherent-Holistic (all stages)

In this section we refer to the last space you visited - Stage 3 - The projected room with many doors with bottle and a cookie box.

(1) I do not agree at all	*(2)*	*(3) I somewhat agree*	*(4)*	*(5) I fully agree*

I was able to imagine the arrangement of the spaces presented in the "Stage 3" environment very well.
I had a precise idea of the spatial surroundings presented in the "Stage 3" environment.
I was able to make a good estimate of the size of the presented space.
I was able to make a good estimate of how far apart things were from each other.
Even now, I still have a concrete mental image of the spatial environment.
Even now, I could still find my way around the spatial environment in "Stage 3".
I knew what actions I should take to do to go out.
I could relate my actions with the events that are happening around me.
I could concentrate on what is happening in the environment rather than the mechanisms behind them.

When I took actions(drink or take a cookie) I felt like

(1) I do not agree at all (2) (3) I somewhat agree (4) (5) I fully agree

I am getting bigger or smaller.
The environment is getting bigger or smaller.
I felt the relative size of me and the environment is changing.
I felt like-I felt like I was changing.
I felt like the environment was changing.

How familiar do you think you are with...

(1) Not at all (2) (3) Somewhat (4) (5) Very much

The story "Alice's Adventures in Wonderland" by Lewis Carroll?
The characters in "Alice's Adventures in Wonderland" story?
The events taking place in "Alice's Adventures in Wonderland" story?
The character of "Alice" in the "Alice's Adventures in Wonderland" story?

In the story "Alice's Adventures in Wonderland" by Lewis Carroll there is:
A caterpillar that smokes a pipe
A butterfly that flied down the rabbit hole with Alice
A rabbit that carries a pot of tea

In the story "Alice's Adventures in Wonderland", by Lewis Carroll, at the beginning Alice sits in the garden:
With the king
With her sister
With her dog

Have you watched movies or animations inspired by the story "Alice's Adventures in Wonderland"? [Yes/No]
Have you played games inspired by the story "Alice's Adventures in Wonderland"? [Yes/No]
Do you have any other experience related with the "Alice's Adventures in Wonderland" story? [Yes/No]

Thank you very much for your participation! Please close the lap top when you are finished and wait we will join you for a short interview.

Questions used in the semi-structured interview:

How did you like it?
Why did you do certain actions? What triggered you?

What do you want to see better in your next experience?
Would you recommend it to a friend?
Would you pay for it?

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Acknowledgments

There are many people who contributed to this dissertation. First, I would like to thank my first promotor prof.dr. Matthias Rauterberg, for giving me the opportunity to join the Designed Intelligence Group and the ALICE project. Thank you Matthias for the support with many means during these years! I would like to thank my second promotor Berry Eggen for his support whenever I needed to consult him. I want to thank to dr. Geert Langereis, with whom I started the first brainstorming about my research project. Thanks to dr. Jun Hu, who joined as a project manager of the ALICE project and was part of my supervision team from the beginning to the end. I would like to thank to dr. Mathias Funk, who joined the team when it was necessary. Thank you, for helping me when I was feeling lost, and supporting me to finish the writing of the thesis. I also expres my sincere appreciation to the members of the reading committee: prof.dr. Ryohei Nakatsu, prof.dr. Dirk Heyen and prof.dr. Lynda Hardman for reviewing this thesis and providing me with very valuable feedback on my manuscript.

Many people worked together with me on the ALICE project and gave significant input to this thesis. I want to thank all the Wonderlanders for the awesome journey we had together: Geert van Boomen, who was always there to help; Chet Bangaru, for the extraordinary effort to answer on all the unorthodox requirements from the Wonderlandish environment; Richard Kennedy, for the 'enlightenment' efforts; Jeroen Bun, for joining the 'be brave' adventure; Anika van der Sanden, for 'walking the debugging walk'; and to Nikolai Gillisen for all the effort 'behind the scenes'. Many thanks to everyone else that joined the ALICE project: Jasen Markovski, Jifei Ou, Muamer Ajlamovich, Angeliki Siolios, mr. Fan, Casper Vos, and Ansgar Silles. Thank you for your creativity, enthusiasm, patience, and ambitions. I enjoyed working with all of you!

Sharing the office with intelligent, friendly and cheerful people was a bless of its own. I spent awesome years together with Sibrecht, Misha, Bram, Alex, Gerrit, Roman, Huang Ming, Idowy, Fulya and Dominika. Thank you all for the great lunch talks, drinks, dinners, laughs, travelings, bitterbolen and frikandel special! Thank you for joining the yoga lessons and the endless discussions. You made these four years very special!

Also, I would want to thank all the people I met during these years in the Netherlands, for the awesome times we spent together. Thanks to all my friends and relatives from Macedonia for the fun times in our travels and special occasions. I have to mention Dijana, Hristina, Marija, Aco, Nikola and my aunties Milka and Ljubica. Thank you for being available always for our online talks whenever I felt distanced in a foreign country, you were always there!

And at last, I thank my family for all the support and love they gave me along the way. To my sister for her wholeheartedly support, which sometimes meant brainstorming about my PhD project, alongside thinking about my future and always believing in me. I want to thank to my lovely Ana, who on the age of six forewarn me and acknowledged that it is “very difficult to write a book”! I have no means to thank to my mother for everything she did for me to support me through my education and life decisions, being the background force and unselfish giver of much more than one can imagine. I want to thank my father for filling my heart with love and respect, giving me inspiration and lovely memories for a life time.

My story gets complete with the warmth and peace I found in my home. Thank you, Boris, for being as you are, my safe heaven and life travelling companion. Cheers to the years that we spent together in the PhD endeavour and to everything that life will bring to us in the future.

Curriculum Vitae

Marija Nakevska was born on 16th of November 1981, in Shtip, Macedonia. She graduated with major in Computer Science at the University of Natural Science and Informatics, Skopje, Macedonia. She has several years of working experience in the development of different information systems, secure web applications, banking software and in research and development of different web and community networks. She has joined the Designed Intelligence group at the Industrial Design Department, Eindhoven University of Technology, in August 2010. This dissertation is the result from the PhD research on the topic "Interactive Storytelling in Mixed Reality".