TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

D I S S E R T A T I O N

Engineering 3D Virtual World Applications
Design, Realization and Evaluation of a 3D e-Tourism Environment

ausgeführt zum Zwecke der Erlangung
des akademischen Grades eines
Doktors der technischen Wissenschaften

unter der Leitung von

ao. Univ. Prof. Mag. Dr. Dieter Merkl
E188 Institut für Softwaretechnik
und Interaktive Systeme

eingereicht an der
Technischen Universität Wien
Fakultät für Informatik

von

Dipl. Ing. Ingo Seidel
Matrikelnummer: 0105181
Wehlistrasse 159/17
A–1020 Wien

Wien, am 17. Mai 2010
Datum

Unterschrift

Kurzfassung

Eine virtuelle 3D Welt ist eine dreidimensionale Umgebung, in welcher die Benutzerinnen und Benutzer durch eine dreidimensionale Figur, einen Avatar, verkörpert werden. Sie sind in der Lage sich in dieser 3D Welt zu bewegen, mit ihr zu interagieren und mit anderen Benutzerinnen und Benutzern zu kommunizieren. Die Popularität und Verbreitung von virtuellen 3D Welten ist in den letzten Jahren stetig gestiegen und mittlerweile verbringen Millionen von Menschen regelmäßig ihre Zeit in solchen Welten. Es ist daher notwendig das Potential dieser neuen Technologie zu erforschen, um die Bedürfnisse der Benutzerinnen und Benutzer zu verstehen und Methoden zur Erstellung effektiver Applikationen zu entwickeln.

Die Verwendung von 3D Welten ist für Firmen, Regierungsorganisationen, Universitäten und Forschungseinrichtungen von Interesse. Erwähnenswerte Beispiele hierfür sind universitäre Lehrveranstaltungen, die in einer 3D Welt abgehalten werden, aber auch der Versuch von Unternehmen, 3D Welten als Marketinginstrumente für ihre Produkte zu verwenden. Dennoch werden die spezifischen Eigenschaften dieser virtuellen Umgebungen oft nicht richtig verstanden und es fehlt an Erfahrung in der Entwicklung von 3D Welten.

In dieser Arbeit präsentieren wir daher ein holistisches Entwicklungsmodell, welches auf die Entwicklung von Applikationen in virtuellen 3D Welten zugeschnitten ist. Das Modell vereinigt das Wissen aus den Bereichen der Software Entwicklung, virtueller 3D Welten und virtueller Realität, mit dem Ziel, einen effizienten und flexiblen Prozess zur Verfügung zu stellen, der alle Phasen des Entwicklungszyklusses abdeckt. Die grundlegende Struktur basiert dabei auf einer iterativen und inkrementellen Vorgehensweise, welche von einem etablierten Software Entwicklungsprozess, dem “Rational Unified Process”, abgeleitet worden ist. Diese generelle Struktur wird in der Folge auf die Entwicklung von Anwendungen in virtuellen 3D Welten angepasst und das daraus resultierende Entwicklungsmodell wird im Detail beschrieben.

Dieses Entwicklungsmodell ist das Ergebnis unserer Forschung im Bereich von virtuellen 3D Welten, wo wir eine agentenbasierte 3D e-Tourismus Umgebung entwickelt haben. Die Entwicklung dieser Umgebung half uns einerseits dabei die Eigenschaften und Besonderheiten von virtuellen 3D Welt zu verstehen und ermöglichte es uns andererseits, Benutzerstudien in einer virtuellen 3D Welt durchzuführen. Ein agentenbasierter Zugang wurde gewählt um den Benutzerinnen und Benutzern einen einheitlichen Zugang zu verschiedenen Informationsquellen zu ermöglichen, welche von Software Agenten aufbereitet und in der 3D Welt präsentiert werden. Die Geschäftsprozesse und angebotenen Dienstleistungen sind im Agentensystem definiert und werden ebenfalls über die 3D Welt zugänglich gemacht.

Diese Umgebung wurde anschließend in einer qualitativen Benutzerstudie evaluiert um die Akzeptanz von virtuellen 3D Welten im Tourismus zu erforschen und zu überprüfen, ob virtuelle 3D Welten für Aufgaben im “realen” Tourismus geeignet sind. Die Evaluierung wurde deshalb anhand eines realen Anwendungsfalles konzipiert, in welchem die Benutzerinnen und Benutzer zwei Hotelzimmer buchen mussten. Es nahmen insgesamt 20 Testpersonen an der Evaluierung teil, wodurch wir wertvolle Erkenntnisse über die Kombination von 3D Welten und Tourismus gewinnen konnten. Die Resultate zeigen, dass die Benutzerinnen und Benutzer in der Lage waren die Navigations- und Interaktionsmetaphern schnell zu erlernen und dass virtuelle 3D Welten neue Möglichkeiten für den Tourismus, wie zum Beispiel 3D Produkte, eröffnen können.

Abstract

A 3D Virtual World is a three dimensional environment in which the user is impersonated as an avatar and is able to interact, communicate and move around within this 3D space. 3D Virtual Worlds have seen a rise in popularity during the last decade, due to the increasing performance and prevalence of the required hardware. It is necessary to study the capabilities of this new technology, to understand the users needs and to identify methods for the creation of effective applications.

There is a need by different parties such as businesses, governments, research facilities or universities to utilize 3D Virtual Worlds for their purposes. Examples include university lectures that are conducted in 3D Virtual Worlds or the effort of corporations to utilize 3D Virtual Worlds as marketing instruments to promote their products. However, often the characteristics of these environments are not well understood and the level of experience in developing 3D Virtual World applications is rather limited. In this thesis we therefore propose a holistic process model that is tailored at the development of applications in 3D Virtual Worlds. The model aggregates the knowledge of related work in the areas of software engineering, 3D Virtual Worlds and Virtual Reality to create a powerful and flexible process that covers all stages of the development cycle. The general structure follows an iterative and incremental process that is based on a well established software engineering process - the Rational Unified Process. This general structure is then tailored at the development of 3D Virtual World applications and the derived holistic process model is presented.

The process model is the outcome of our research in 3D Virtual Worlds where we created an agent-based 3D e-Tourism environment. The development of the environment helped us to establish an understanding of the properties of 3D Virtual Worlds and provided us with a research testbed for conducting user studies in 3D Virtual Worlds. An agent-based approach was taken in order to provide unified access to disparate information sources which are aggregated and provided by software agents in the 3D Virtual World. The business processes and services are defined in the agent system and are accessible to end users via the 3D Virtual World. This research testbed was then used in a qualitative user study to evaluate the acceptance of 3D Virtual Worlds in the tourism domain and to investigate the suitability of 3D Virtual Worlds for real world tourism tasks. The evaluation was designed along a use case in e-Tourism in which users had to book two hotel rooms. A total of 20 test users participated in the evaluations which provided us with valuable insights. The results show that users were able to quickly adopt the navigation and interaction metaphors used in the environment and indicate that 3D Virtual Worlds can provide new opportunities for tourism, such as 3D products.

Acknowledgments

The writing of this thesis was made possible in the first place through Helmut Berger who provided me with the opportunity to work in the Itchy Feet project. Besides being a great project leader, he always took the time to listen to my ideas as well as concerns. He supported me during every stage of the thesis and was a marvelous reviewer who provided insightful comments and helped to shape and improve the quality of my publications. I am equally grateful to Dieter Merkl who did a terrific job in supervising my thesis. I will not forget the long hours of discussion that not only helped me to find the right direction for my thesis, but during which I also learned a lot about university structures and university politics. I would also like to express my thanks to all the members of the Itchy Feet project team with whom it was a pleasure to work with. Markus Gärtner who impressed me with his work enthusiasm and technical knowledge, Josef Froschauer whose pragmatism was a source of inspiration and Michael Pöttler who fascinated me with his "can do" attitude.

From a personal perspective, my greatest thanks go to my parents, Brigitte and Reinhard. They supported me throughout all my years of study on a personal as well as financial level and provided me with great motivational and emotional support. Finally, the one who probably deserves the most acknowledgment of all is my girlfriend Miriam. She was always there for me, accompanied me through the good and hard times of writing this thesis and believed in me at any time.

Contents

CHAPTER 1

Introduction

Starting with the first 3D computer games at the end of the 1990s, 3D technology has matured ever since leading to the emergence of online social virtual worlds where people meet and socialize in a 3D space. A prominent example is Second Life[1], a social virtual world that was pushed by a huge media hype in 2007. During this time the number of users increased exponentially and by the end of 2009 Second Life had 13 million registered users. A constant user base had been established and in 2009 there were 10,000 to 40,000 people online at any time. While Second Life is one of the social virtual worlds that is best known, many other worlds have emerged in the last years. In a report of the Serious Games Institute, de Freitas (2009) identified eighty existing 3D Virtual Worlds with another hundred planned to be launched during 2009.

3D Virtual World technology has also been adopted by the research community. One of the earliest works where a 3D computer game was used in research, was a frontend for process management on UNIX systems (Chao, 2001). Since then, different research disciplines have started to investigate 3D Virtual Worlds. This ranges from e-Learning (Dieterle, 2009) to works that study the economics in 3D Virtual Worlds (Castronova, 2006) to psychological studies of the participants of these environments (Yee, 2006). Bainbridge (2007) has highlighted the scientific research potential of 3D Virtual Worlds and researchers have exploited the unique characteristics of 3D Virtual Worlds to create more usable systems (Moloney et al., 2003; Kot et al., 2005). When developing a 3D Virtual World it is especially important to understand its characteristics and how they can be applied to make an application more effective. The need for a structured development process which takes into account the added complexity of the third dimension, the different nature of interaction as well as different usability challenges has been

[1] http://secondlife.com (last accessed 02.05.2010)

expressed by several researchers who have also proposed development methodologies (Wilson et al., 2002; Sánchez-Segura et al., 2003; Gabbard et al., 1999; Menchaca et al., 2005). Such methodologies usually focus on certain stages of the development cycle (Gabbard et al., 1999) and/or are designed for a specific technology (Menchaca et al., 2005). Few methodologies exist that cover the whole life cycle from the start of the project to the end of the project. However, especially for people who are new to application development in 3D environments, a holistic process model that provides help during all stages of the development is essential in order to build effective applications. The first research goal of this thesis follows from these considerations:

Research Goal 1 *Creation of a holistic process model for application development in 3D Virtual Worlds that (i) covers the whole development life cycle, (ii) enables 3D technology novices to get engaged in the realization of 3D applications and (iii) can be applied in different types of 3D environments.*

The principal structure of the process model is based on a software engineering process, the Rational Unified Process (RUP) (Kruchten, 2006), and borrows ideas from works in the areas of Virtual Reality and 3D Virtual Worlds. Key characteristics and methods were identified and an iterative, architecture centric and use case driven principal structure was developed. We identified two essential characteristics for the development of 3D Virtual Worlds that did not receive much attention up to now. The first is an introductory phase that is intended for novices in 3D Virtual World application development. This phase conveys the unique characteristics of 3D environments and outlines the differences to 2D interfaces such as interaction and navigation metaphors. The second characteristic is a process for the selection of an appropriate 3D Virtual World technology. Each application has a unique set of features and what might be easily achievable in one 3D Virtual World can be impossible in another. Great care needs therefore to be taken when deciding upon the technology to realize the application.

The process model was developed in the course of a research project with the principal goal of investigating the applicability of 3D Virtual Worlds to the e-Tourism domain. In the last decades Information and Communication Technology (ICT) has revolutionized the global economy and almost every business including tourism (Buhalis and Law, 2008). The rapid evolution of ICT enabled consumers to have access to a broader range of information services covering the whole tourism life cycle (Werthner and Klein, 1999). An increasing number of tourism offers are booked over the Internet and people use the Internet for the information search, for the comparison of prices and to share their travel experiences online. However, online shopping experiences are often regarded to be impersonal and anonymous without face-to-face communication (Cyr et al., 2007). Hassanein and Head (2007) showed that the social presence, which is the sense of awareness of other people in a communication medium, can be influenced by the user interface. This, in turn, influences the trust, enjoyment and perceived usefulness of a Web site. 3D Virtual Worlds prove especially useful in this regard, as they implicitly address social interaction. Similar to the real world, a user can see other users, is able to walk towards them and can start talking to them. It is fairly easy to get in touch with other people and new relationships can be formed easily.

Another important aspect in tourism is the presentation of products. A tourism product is a virtual product that cannot be experienced in advance - it is a confidence product (Gratzer et al., 2004). For a customer it is essential to get a good impression of the product before the trip. Traditionally, the impression of a destination is conveyed by means of quality photos in travel catalogs and information from the travel agent. Textual descriptions and pictures are used to illustrate travel destinations. An approach that goes beyond these "classical" media types and provides more sophisticated visualization of tourism products are 3D product presentations. In the context of e-Tourism, a 3D product might be a 3D representation of a hotel room or a replication of an entire guest house. The user is then literally able to walk through the building and can perceive the environment as if being on site. This helps in getting a detailed impression of the product and creates a completely new product experience. These insights motivate the second research goal:

Research Goal 2 *Provide a 3D e-Tourism environment (i) for providers and consumers, to facilitate versatile interaction between participants including the trade of tourism products (ii) that acts as a community facilitator to create and establish a lively and sustainable community (iii) that is information-rich and provides transparent and unified access to disparate multimedia information sources and (iv) whose technological basis can be applied to other domains as well.*

The technological basis for this environment is a 3D Virtual World that allows users to participate in the environment. The 3D Virtual World offers various community features such as profiles or forums, in order to become the cornerstone of a lively tourism community. Users have access to a wide range of information sources that are aggregated and presented in the 3D Virtual World. In order to provide these functionalities an agent-based approach is taken. According to Woolridge (2001, p. 226), agent-based solutions can be employed whenever the information is spread across several sources. Multiple distributed software agents can then be used to provide access to these data sources and to aggregate and prepare the respective information. This perfectly applies to the tourism domain where information is spread over the Internet and stored in databases on different organizational levels (regional, national, international). The software agents reside in a Multi-Agent System that is connected to the 3D Virtual World. To this end, we developed a Middleware that connects a Multi-Agent System methodology, namely Electronic Institutions (Esteva et al., 2001) with 3D Virtual Worlds. The system is based on a three layered architecture. The 3D Virtual World is placed at the top layer, the Electronic Institution is at the bottom layer and both these two components are connected through the Middleware. An Electronic Institution is similar to a real world institution where processes and rules are predefined and involved parties have to act according to these processes and rules. They define the regulatory framework for the 3D Virtual World and contribute to the security and the trust of the whole system.

In order to understand how users interact in 3D Virtual Worlds, empirical user studies are necessary. Some examples of such studies can be found in the literature (Tromp, 2001; Singer et al., 2008). However, many evaluations neglect the application domain and focus on the evaluation of general concepts or the comparison of certain technologies. Evaluations tend to take place in an abstract environment where users have to navigate through a labyrinth or are required to move objects from one location to another (Chittaro and Burigat, 2004; Tan et al., 2001; Modjeska and Waterworth, 2000). An aspect which is often overlooked is embedding the evaluation in an application context (Hix and Gabbard, 2002). In this thesis we are addressing this shortage and the 3D e-Tourism environment was designed to support real world e-Tourism services. This ranges from the initial planning phase to the product selection to the actual payment. The goal was to evaluate these services in a qualitative user study in order to learn about the applicability of 3D Virtual Worlds in the tourism domain. These considerations lead to the third research goal:

Research Goal 3 *Conduct a qualitative user study of the 3D e-Tourism environment that has the goal (i) to evaluate the usability and system performance of the environment, (ii) to research the provided communication and interaction facilities in the context of e-Tourism, (iii) to research the potential of e-Commerce for tourism in a 3D Virtual World and (iv) to investigate navigation metaphors in 3D Virtual Worlds.*

The user study was designed along a real world tourism use case and users had to perform the same activities they would normally perform when planning their trip. This started with an initial information search to find out the travel destination. They then had to coordinate their plans with another user and talk to a travel agent to find out which hotels are recommended. Finally, one hotel had to be booked in a travel agency, while the other hotel had to be bought in an auction. A total of 20 test users successfully participated in the evaluation and the results show that the created environment is usable, can be used by novice users and that they are interested in certain features that are provided by a 3D e-Tourism environment.

1.1 The Itchy Feet Project

The work reported in this thesis was carried out within a three year project funded by the Austrian Science Fund (FWF) with the project reference number L363[2]. The project started in May 2007 and was completed in July 2010. The principle goal of the project was the creation of a novel 3D e-Tourism environment and to research the potential of 3D Virtual Worlds in the context of e-Tourism. This principal goal subsumed the following three goals:

- Provide a 3D e-Tourism environment for providers and consumers that enables versatile interaction between participants including the trade in tourism products.
- Provide a 3D e-Tourism environment that becomes a community facilitator to create and establish a lively and sustainable community involving both, providers and consumers.
- Provide a 3D e-Tourism environment that is information-rich and multimedia-based to offer transparent and unified access to disparate information sources.

The role model of this environment are Massively Multiplayer Online Role-Playing Games (MMORPGs) which are game based 3D environments in which thousands of players participate simultaneously. Players interact and collaborate with each other in this spatial three dimensional space. In the same manner, the 3D e-Tourism environment should facilitate the communication and interaction between consumers and providers. The lack of regulation in existing 3D environments and the access to information sources is provided through software agents. The business processes are explicitly defined in the Multi-Agent System and the adherence to the defined rules and processes is verified by the Multi-Agent System. To this end, we first developed a general framework that connects the Multi-Agent System with a 3D Virtual World. The general framework was then used in the next step to create the 3D environment in the tourism domain. This included the development of data models and business logic, the design of the 3D world and the implementation of a 3D client enabling users to participate in the world. The

[2] http://www.fwf.ac.at/de/abstracts/abstract.asp?L=D&PROJ=L363 (last accessed 02.05.2010)

created environment was evaluated and additional extensions to the environment were realized within the project. A serious gaming application was developed to communicate Japanese culture and etiquette. In this game the user slips into the role of a tourist who has to locate her host in a small Japanese village. In order to achieve this goal, the user has to complete several quests during which she learns about Japanese culture and etiquette in a playful way. The environment was further extended by a hybrid semantic search system that combines keyword and semantic search. The system extracts and aggregates semantic information from arbitrary Web sites and builds a search corpus upon which keyword as well as semantic queries can be issued. This enables users to specify the search query more explicitly by directly selecting semantic concepts and combining them with individual search terms.

Figure 1.1: The Itchy Feet project team.

The project team is depicted in Figure 1.1 showing Helmut Berger, the project leader, Dieter Merkl, the scientific supervisor and the four PhD students: Ingo Seidel, Markus Gärtner, Josef Froschauer and Michael Pöttler. Markus and Ingo where involved in the project from the beginning. Ingo was responsible for developing the technological framework of the 3D environment, creating an initial 3D Virtual World and conducting user studies in the world. Markus developed the business logic in the Multi-Agent System layer and worked on the integration of disparate information sources via software agents. As part of this work he developed the hybrid semantic search system that combines keyword and semantic search. Michael Pöttler was working in the project for half a year in

2008 where he focused on the topics of community and game design in order to understand how a sustainable community can be created. Josef Froschauer joined the project in 2009 and was responsible for the creation of the 3D Virtual World. Additionally, he carried on with Michael's work on game design and created the serious gaming application for communicating Japanese culture and etiquette.

1.2 Research Approach

The research approach of this thesis is based on the design-science research paradigm and is embedded in the Information Systems Research Framework which was proposed by Hevner et al. (2004). This framework contains guidance on how to conduct, evaluate and present design-science research in the context of information systems. A graphical illustration of this framework is presented in Figure 1.2. The research activity is depicted in the middle of the Figure and is framed by the environment and the knowledge base. There are two different types of research which are conducted in different phases and complement each other. In the behavioral-science research phase, theories are developed and justified. In the design-science research phase, an artifact is build and evaluated. The research is embedded within the environment and driven by a business need that is of relevance in this environment. The relevance of the research is justified through the business need. The knowledge base is the repository of aggregated foundations and methodologies from previous information systems research. The foundations inform the develop/build activity and provide underlying frameworks, theories and instruments upon which the research is conducted. The methodologies provide guidance on how to justify/evaluate the outcome of the research. The rigor captures the appropriate application of the foundations and methodologies in the research process. The contributions of the research are generated through the application of the artifact in the environment. This produces new knowledge about applying the artifact in the environment and enables the researcher to derive results which then extend the knowledge base.

This thesis is embedded within the research framework as follows. We follow the design-science research paradigm and are building on theories that have been established in previous behavioral-science research. This includes theoretical foundations on e-Tourism, Multi-Agent Systems and 3D Virtual Worlds. The 3D e-Tourism environment is the artifact that is being created. The development is driven by a business need to provide additional utility to customers in the tourism domain through a 3D environment and to develop an understanding of the applicability of such environments. The knowledge base is formed by the related work in the areas of 3D environments, e-Tourism and Multi-

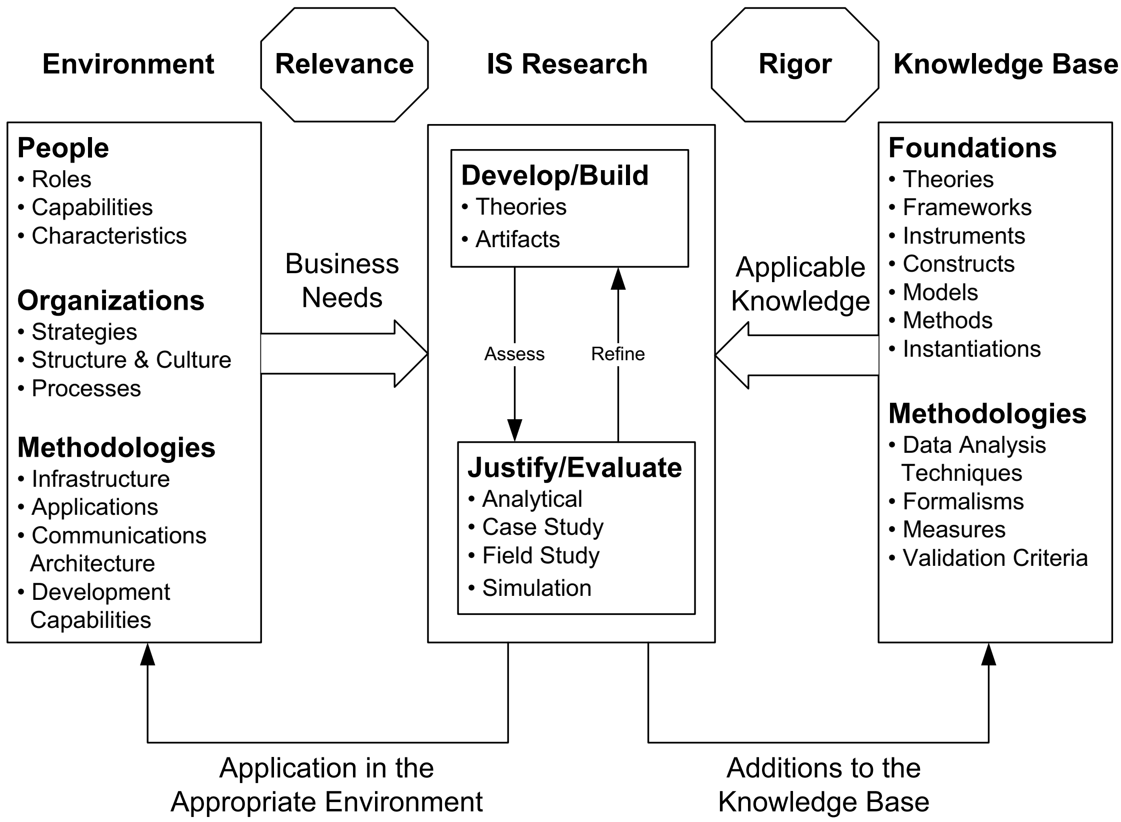

Figure 1.2: The Information Systems Research Framework proposed by Hevner et al. (2004)

Agent Systems that informed the building and evaluation of the artifact. The evaluation of the 3D e-Tourism environment takes place within the context of the business environment and enabled us to learn about the application of 3D environments in the tourism domain. The results of this evaluation form the contribution that is relevant with respect to the business environment (cf. Figure 1.2, the arrow facing left to the environment). The contributions that extend the knowledge base are the proposed process model for application development in 3D Virtual Worlds as well as the provision of a framework that connects a Multi-Agent System with a 3D Virtual World (cf. Figure 1.2, the arrow that is facing right to the knowledge base).

Furthermore, as part of the Information Systems Research Framework, the authors present seven guidelines for conducting design-science research in Information Systems. The *problem relevance* captures the requirement to study problems that are unsolved, relevant to the business environment and provide opportunities that have not been studied yet. The *research rigor* is related to the rigorous application of methods and foundations of the knowledge base during the creation and evaluation of the artifact. *Design as a search process* describes how the solution to the problem is generated. An iterative and heuristic search strategy is proposed as a good and feasible strategy to develop an artifact that is applicable to the environment. The *Design as an artifact* guideline stresses the fact that in design-science research the problem is addressed through the creation of an artifact. The *Design evaluation* guideline describes that the artifact needs to be evaluated with respect to the requirements of the business environment in order to demonstrate the quality and utility of the artifact. The *research contributions* capture the contributions that are generated as part of the research. Three different types of contributions are distinguished: the application of the artifact in the environment produces new knowledge with respect to the environment (left facing arrow in Figure 1.2), the artifact itself as well as created methods or models contribute to the foundations of the knowledge base (right facing arrow in Figure 1.2) and the evaluation may yield new evaluation metrics and measures which are contributed to the methodologies of the knowledge base (right facing arrow in Figure 1.2). Finally, the *communication of research* guideline stresses the importance that the contribution and results of the research are communicated both on a technical as well as on a managerial level. In the following we present how the research approach of this thesis is organized according to these guidelines and explain the structure of our research in detail.

Problem Relevance

First, e-Tourism as well as 3D Virtual Worlds are rapidly growing. Gartner Inc. (2007) predicted that at the end of 2011, 80 percent of the Internet users will be participating in 3D Virtual Worlds and encourages companies to experiment with 3D Virtual Worlds in order to understand their characteristics and potential. Buhalis and Law (2008) state that Information and Communication technologies have truly transformed the whole tourism industry in the last decade and that a wide range of new e-Tourism services and applications were created. At the cutting edge of this evolution lies the application of e-Tourism to 3D Virtual Worlds as a potential application domain for 3D Virtual Worlds. Second, Virtual Institutions are a conceptual framework that combines Multi-Agent Systems with 3D Virtual Worlds (Bogdanovych et al., 2005a). While the theoretical basis for this framework was established in (Bogdanovych et al., 2005a, 2007) and was applied to e-Commerce in general (Debenham and Simoff, 2006) and e-Tourism in particular (Berger et al., 2007), the practical implications still need to be studied. It is therefore necessary to create prototypes, apply them within a real world context and evaluate their utility.

Research Rigor

The research rigor is achieved by building on the theoretical foundations of Virtual Institutions (Bogdanovych et al., 2005a), employing the related work of building software in general (Kruchten, 2006) and 3D environments in specific (Hix and Gabbard, 2002; Bowman et al., 2004; Dang et al., 2008) and utilizing research results from e-Commerce (Hassanein and Head, 2007; Cyr et al., 2007) and e-Tourism research (Gratzer et al., 2004; Schwabe and Prestipino, 2005) to identify improvements over existing systems that can be addressed with a 3D Virtual World (e.g. trust, social warmth, virtual products). The evaluation of the created system also followed a rigorous evaluation process in a controlled environment that has been established in related works (Nielsen, 1993; Livatino and Koeffel, 2008) and the analysis was conducted according to procedures from the literature as well (Lofland and Lofland, 1995; Kuckartz et al., 2008).

Design as a Search Process

The research was conducted as a search process where we first acquired knowledge on the application domain of e-Tourism and on the technical domains of 3D Virtual Worlds and Multi-Agent Systems. This enabled us to understand the required properties of an agent-based 3D e-Tourism environment and allowed us to formulate the principal requirements and system design. The construction of the artifact itself followed an iterative search process to find the optimal solution, both from a technical as well as usability point of view. A technical solution that connects the Multi-Agent System with the 3D Virtual World had to be constructed and a usable solution that enables novice users to use the application had to be created.

Design as an Artifact

The artifact as the central element of the research is the 3D e-Tourism environment itself. The artifact is an instantiation of a Virtual Institution that is applied to the tourism domain. The artifact is both generalizable and specific. It is generalizable in the sense that the principal technical framework can be reused and applied to other domains. It is specific in the sense that we implemented a specific 3D environment in the tourism domain. This allowed us to evaluate the artifact in the business environment and to study the amalgamation of tourism and 3D Virtual Worlds.

Design Evaluation

The functionality and feasibility of the artifact is demonstrated through an empirical user evaluation. The evaluation was conducted within a real word context in order to provide results with respect to the business environment. The evaluation was designed according to evaluation methodologies and approaches of the knowledge base in order to achieve research rigor. The evaluations took place in controlled conditions in order to provide valid results and the analysis was performed rigorously in order to answer the research questions.

Research Contributions

The research contributions of the thesis are threefold. The first contribution is the creation of the artifact itself which provides a testbed for conducting research in Virtual Institutions. Researchers are able to build upon the artifact, to extend it with additional functionality and to apply it to other domains than e-Tourism. The second contribution are the results of the evaluation. They provide information on the application of 3D environments in the tourism domain as well as information on the usability of 3D environments in general. The third contribution is the development and establishment of the process model for building 3D Virtual World applications. The process model captures and aggregates our gained experiences and the results of related works to provide a customized development process for the engineering of applications in 3D Virtual Worlds.

Research Communication

The outcome of the research has been presented from a technical point of view as well as from an application point of view. The technical foundations of the system with a focus on connecting a Multi-Agent System with a 3D Virtual World were presented (Seidel and Berger, 2007), the technical details of the implementation on the agent level were provided (Gärtner et al., 2008), the application of the system to the tourism domain was presented (Seidel et al., 2009a,b) and the results of the evaluation and the derived experiences of our research were presented as well (Seidel et al., 2010a,b). More information on the publication record can be found in the next Section.

1.3 Thesis Outline and Publication Record

The results of the work presented in this thesis and the scientific contribution to the research community have been reported in several peer-reviewed journal publications, conference proceedings and one book chapter. This Section outlines which publications served as the basis for the different Chapters and presents the structure of the thesis.

A proposal that outlined the topic and goals of this thesis was presented at the ENTER 2008 PhD workshop where it also received the best proposal award:

> Seidel, I. (2008). Developing a 3D e-Tourism environment. *Paper presented at the ENTER 2008 PhD Workshop*, Innsbruck, Austria, January 2008.

The proposal focused on the e-Tourism aspects of the thesis and included information on the creation of the 3D e-Tourism environment, the services that will be provided by the environment and which kind of research questions are addressed in the planned evaluation.

The remainder of the thesis is now structured as follows. In Chapter 2, 3D Virtual Worlds are introduced. We provide a definition of 3D Virtual Worlds, explore how they emerged and give examples on different types of 3D Virtual Worlds. Then the research potential of these environments is highlighted and related research works that investigate 3D Virtual Worlds in a scientific manner are introduced. In the following the similarities between Virtual Reality applications and 3D Virtual World applications are explored. We show how research findings of the Virtual Reality domain are applicable to 3D Virtual Worlds and how we have utilized them in our research.

After the concept of 3D Virtual Worlds is established, the three core contributions of the thesis are covered in the following three chapters. In Chapter 3, the process model for engineering 3D Virtual World applications is proposed, in Chapter 4 the 3D e-Tourism environment Itchy Feet is introduced and in Chapter 5, the study on the evaluation of Itchy Feet and the acceptance of 3D Virtual Worlds in the tourism domain is presented.

In Chapter 3 we propose a holistic process model for engineering 3D Virtual World applications that is (i) derived from our experiences from the Itchy Feet project, (ii) based on well established software engineering methodologies and (iii) tailored at 3D Virtual Worlds with input from methodologies in the Virtual Reality and 3D Virtual World domain. A paper on an initial version of this process model was accepted for presentation at the International Conference on Information Society (i-Society '10) and will be published in the conference proceedings:

Seidel, I., Gärtner, M., Froschauer, J., Berger, H. and Merkl, D. (2010). Towards a holistic methodology for engineering 3D virtual world applications. *Proceedings of the International Conference on Information Society (i-Society '10)*. accepted for publication.

This paper provides a brief overview on different development methodologies in the Virtual Reality and 3D Virtual World domains and identifies common methods and characteristics. These insights are then combined with our experiences and an iterative, user-driven and evaluation-based methodology with six consecutive stages is established. In Chapter 3, this methodology is taken one step further and enhanced by concepts from software engineering methodologies. The general process structure of the Rational Unified Process is applied to the methodology resulting in a holistic process model for engineering 3D Virtual World applications.

The 3D e-Tourism environment Itchy Feet is presented in Chapter 4. The system is first presented from a user's perspective illustrating how users participate in the environment via the 3D Virtual World and what kind of services are available in the world. Then, the underlying architecture is explored. The architecture of the 3D e-Commerce framework is presented and the different components are introduced. The generic framework is then applied to the e-Tourism domain and the services of Itchy Feet are presented in detail. It is shown how the connection between the Multi-Agent System and the 3D Virtual World is realized and which business processes are defined on the agent level.

The framework connecting Electronic Institutions with 3D Virtual Worlds was presented at the Intelligent Agent Conference (IAT '07) and was published in the conference proceedings:

Seidel, I. and Berger, H. (2007). Integrating Electronic Institutions with 3D Virtual Worlds, *Proceedings of the 2007 IEEE/WIC/ACM International Conference on Intelligent Agent Technology (IAT '07)*, IEEE Computer Society, Washington, DC, USA, pp. 481-484.

In this paper, the architecture is established on a general level, but is not applied to the e-Tourism domain yet. The application of the architecture to the tourism domain resulting in the Itchy Feet environment is the topic of the following book chapter:

Seidel, I., Gärtner, M., Pöttler, M., Berger, H., Dittenbach, M. and Merkl, D. (2009). *Tourism Informatics: Visual Travel Recommender Systems, Social*

Communities, and User Interface Design, Information Science Reference, Hershey, PA, USA, chapter Itchy Feet: A 3D e-Tourism Environment, pp. 209-242.

In this book chapter, the Itchy Feet system is presented in detail including the definition of the business processes in the Multi-Agent System. Furthermore, the development process is discussed and problems and pitfalls that we faced in the development are reported. While the concept of Itchy Feet was presented in the book chapter, the implementation had not been finished at the time of writing. The final version of the system was then presented at the International Conference on Software Engineering and Knowledge Engineering (SEKE '09) and was published in the conference proceedings:

Seidel, I., Gärtner, M., Froschauer, J., Berger, H. and Merkl, D. (2009). An agent-based centralized e-marketplace in a virtual environment, *Proceedings of the 21st International Conference on Software Engineering and Knowledge Engineering (SEKE '09)*, Knowledge Systems Institute Graduate School, Skokie, IL, USA, pp. 218-221.

In this paper, the focus is laid on the market mechanisms of Itchy Feet. It is illustrated how an agent-based e-Marketplace was created in a 3D Virtual World and the market mechanisms of Itchy Feet are introduced.

Chapter 5 reports on the empirical user study that was conducted in Itchy Feet to evaluate the acceptance of 3D Virtual Worlds in the tourism domain on the one hand and to evaluate the usability of Itchy Feet on the other hand. A total of 20 test users participated in the evaluations where they had to complete a series of tasks which were based on a real world tourism use case. The evaluation design, the goals of the evaluation and the results are presented and discussed in Chapter 5. While some first results of the evaluation are presented in the following journal paper:

Gärtner, M., Seidel, I., Froschauer, J. and Berger, H. (2010). The formation of virtual organizations by means of electronic institutions in a 3d e-tourism environment, *Information Sciences, Special Issue: Virtual Agent and Organization Modeling: Theory and Applications*. in press.

a detailed description of the evaluation is the topic of a journal paper that was submitted to the Journal of Human-Computer Studies and which is currently under review:

Seidel, I., Gärtner, M., Froschauer, J., Berger, H. and Merkl, D. (2010). A qualitative evaluation of a 3d e-tourism environment, *International Journal of Human-Computer Studies*. submitted for publication.

Finally, the thesis is concluded in Chapter 6. The results of the thesis are summarized and possible directions for future work and future research are given.

CHAPTER 2

3D Virtual Worlds

2.1 Definition and History

The term 3D Virtual World can encompass a wide range of different 3D environments and there is no generally agreed upon definition for this term. Depending on the context in which it is used, people might be referring to quite different environments with the same word. This can range from 3D environments in the Virtual Reality domain to augmented reality environments to desktop based 3D Virtual Worlds which we are addressing in our research. In order to clarify our notion of 3D Virtual Worlds the following definition is provided.

Definition: *A 3D Virtual World*

- is a computer generated three dimensional interactive spatial environment in which users are represented as avatars
- is executed on ordinary desktop computers where the world is viewed through the monitor and operated with keyboard and mouse
- is a multi user environment that provides interaction and communication facilities

In a 3D Virtual World the user is impersonated as an avatar. An avatar is a three dimensional character that is controlled by the user and whose figure usually resembles a human like body. The user is able to move around with the avatar in the 3D space and can interact with the environment. The type of movement varies across different 3D Virtual Worlds. In the most restrictive form, the avatar can only be moved along predefined positions in the 3D Virtual World. When a new position is selected, the avatar disappears from the current location and instantly appears at the new location. The most prevalent type of movement is free movement in the form of walking. The user is then able to explore the 3D space by walking around with the avatar. More sophisticated forms of movement include flying and driving around with vehicles that can be mounted by the avatar.

A 3D Virtual World is interactive and the user is able to interact with elements of the world and with other users. The interaction with objects can range from simple descriptions that are printed out when the user clicks on an object to complex machines that can be controlled by the user and which might illustrate a technical process. The objects are either provided by the platform itself or they are created by the users. The interaction between users is another essential characteristic of 3D Virtual Worlds. The same interaction metaphors as in the real world apply - an interaction is initiated by walking towards another user and starting to communicate. Like in the real world, users that communicate with each other are standing together as a group in the virtual space. In case of lectures, speeches or public talks, the speaker is standing on the podium and the listeners stand or sit around the podium and listen to the speech. Besides the interaction in the 3D space, interactive 2D user interface elements are typically either overlaid on the viewport or are accessible outside the 3D view. The user is then able to invoke certain functions by clicking on the respective interface elements.

The communication and information exchange between members of a 3D Virtual World enables the formation of a user community which is the cornerstone of social 3D Virtual Worlds. Social 3D Virtual Worlds provide a 3D interactive space where people can socialize with each other. In contrast to game based 3D Virtual Worlds, they do not have a clearly defined game objective and are foremost about communication with other users (although game play may be a part of social 3D Virtual Worlds). Social 3D Virtual as well as game based 3D Virtual Worlds emerged from two different computer game genres. The multi-user aspect and the interaction between users have their source in so called Multi User Dungeons (MUDs), whereas the technological foundation has its roots in 3D computer games. A MUD is a text based role playing game which is played by multiple users simultaneously. The commands are typed into a console and the actions that are happening in the world are printed onto the screen. The structure of the world is also communicated through text. For example, if a player enters a building the following text might be printed out: "You have entered the tavern. There are windows on the right and left side, the counter is on the opposite of the entrance and there is a back door on the right side of the counter. There are five other people in the room, three of them are sitting at tables and two are standing at the counter." Players are able to communicate with each other via the text chat, can explore the world together and are able to trade items with each other. Another important characteristic of MUDs is the persistence of data. The world is not executed on the player's computer, but all players connect to a central server that holds the state of the world. The server is running constantly and when a player logs off, the state of the virtual character (inventory, achievements) is stored on the server. When the player logs back in again, she finds her virtual character in the same state and can continue to explore the world. The term MUD was coined by the first game of that genre which was called MUD and developed in 1978 at the Essex University[1]. On the official website it is called the "oldest virtual world in existence" and it can also still be played there. Other popular MUDs include the TinyMUD[2], the DikuMUD[3] and the LPMUD[4].

In terms of 3D computer games, the first sources date back to 1974 when a 3D space simulation called Spasim was created[5]. The game also included network support and was one of the first, if not the first, multi-player 3D computer game. The objects and space ships in this game are visualized as 3D wireframe models and the player can explore the universe, move from planet to planet and fight against other space ships. Other notable historic 3D computer games include Maze War[6], a maze game in which the player navigates through a 3D maze and can shoot other players when they get into the line of sight, the 3D Monster Maze[7], a game in which the player has to navigate through a maze without being eaten by a Tyrannosaurs Rex and Doom[8], a first person shooter which is often attributed to have popularized this genre and was the first 3D computer game that reached millions of players. The combination of 3D technology with the role playing concepts of MUDs then led to the first Massively Multiplayer Online Role-Playing Games (MMORPGs). They combine 3D graphics and persistent world servers to provide a 3D game universe connecting thousands of players. Players are able to interact and collaborate with each other in a 3D space and they constantly improve their avatar to reach the next avatar level. To name but a few examples, Ultima Online[9] started in 1997 and, similar to Doom in the first person shooter genre, is said to have popularized MMORGPs.

[1] http://www.british-legends.com/ (last accessed 02.05.2010)

[2] http://toccobrator.com/classic.htm (last accessed 02.05.2010)

[3] http://www.dikumud.com (last accessed 02.05.2010)

[4] http://www.lpmuds.net/ (last accessed 02.05.2010)

[5] http://web.archive.org/web/20010410145350/http://www.geocities.com/jim_bowery/spasim.html (last accessed 02.05.2010)

[6] http://www.digibarn.com/history/04-VCF7-MazeWar/ (last accessed 02.05.2010)

[7] http://www.zx81stuff.org.uk/zx81/generated/tapeinfo/0/3DMonsterMaze(NGS).html (last accessed 02.05.2010)

[8] http://rome.ro/games_doom.htm (last accessed 02.05.2010)

[9] http://www.uoherald.com/news/ (last accessed 02.05.2010)

EverQuest[10] is a popular fantasy MMORPG that is in existence since 1999 and World of Warcraft[11] which, with its more than 10 million subscribers as of January 2008, holds the Guinness World Record as the most popular MMORPG in terms of subscribers (Glenday, 2009, p. 241).

The development of social 3D Virtual Worlds can be traced back to the mid 1990s as well. Around 1995 several social 3D Virtual Worlds started to emerge such as Cybertown[12] and Active Worlds[13] which are still in existence today. In these social 3D Virtual Worlds the avatar also plays a central role. However, unlike to MMORPGs where the goal is to improve the avatar to the next level, the avatar is rather understood as a virtual representation of the user. A social 3D Virtual World provides an interactive space in which the user is able to communicate and interact with other users. There is no game objective and these worlds are rather about chatting and socializing than achieving a certain game objective. Additionally, in many of these worlds, the environment itself is created by the users and the 3D Virtual World becomes a collectively created space that is driven by the user community. As of 2010, Second Life is one of the most well known and populated social 3D Virtual Worlds with thousands of regular users. More information on the history of 3D Virtual Worlds can be found on the Virtual Worlds Timeline website[14] as well as on the project web site of the Preserving Virtual Worlds project[15] which has the goal to preserve representative cases of 3D Virtual Worlds for future generations (Lowood, 2009).

While the results of this thesis are applicable to any type of 3D Virtual World, including game based, the focus is on social 3D Virtual Worlds that provide a communication and collaboration platform to their users.

2.2 3D Virtual World Examples

In order to get familiar with the concept of 3D Virtual Worlds and to provide the reader with an overview on features and services of 3D Virtual Worlds, five different 3D Virtual Worlds are presented in the following. We will have a look at the economic model, the community and the distinct characteristics of each world. The focus of every world will be highlighted and features that are relevant to the presented worlds will be introduced.

[10] http://everquest.station.sony.com/ (last accessed 02.05.2010)
[11] http://www.worldofwarcraft.com/ (last accessed 02.05.2010)
[12] http://www.cybertown.com/ (last accessed 02.05.2010)
[13] http://www.activeworlds.com (last accessed 02.05.2010)
[14] http://www.vwtimeline.com/ (last accessed 02.05.2010)
[15] http://www.stanford.edu/group/htgg/cgi-bin/mediawiki/index.php?title=Preserving_Virtual_Worlds (last accessed 02.05.2010)

Second Life

Second Life[16] is one of the most prominent and widely used 3D Virtual Worlds. According to the official website it is the "Inernet's largest user-created 3D virtual world community". The world is operated by Linden Lab[17], has one of the largest user bases with more than one million users logged in during March 2010[18] and is also one of the few 3D Virtual Worlds that generates a revenue. There are three primary sources of income: monthly land use fees, premium membership fees and general fees such as transaction fees for exchanging real world money to the in-world currency.

Second Life has two fundamental cornerstones: the user community and user-created content. It provides a wide range of community facilities like text chat, voice chat, instant messaging and forums. Users meet each other in the world in order to socialize, to get to know new people and to participate in events which can be organized in the world. The users express themselves via their avatar and the status of an user is partly determined by the appearance of the avatar. The appearance can be altered with a powerful in-world avatar editor. From the shape of the body to the density of the eyebrows to the length of the feet, nearly every aspect of the body can be modified. The clothing of the avatar plays an important role as well. Some basic clothes are provided for free, while more prestigious clothes have to be bought. The currency in Second Life is the Linden Dollar which can be exchanged to US$ on the official LindeX dollar exchange. The exchange works in both directions. It is possible to buy Linden Dollars for US$ and Linden Dollars that are earned in the world can also be exchanged back to US$. It is therefore possible to make real money in Second Life and there have been reports of people who became millionaires through Second Life[19]. Items are traded on the marketplace and people can either make money by selling objects they have created or via the property market. There are different types of land in Second Life which can either be purchased directly from Linden Lab or bought and rented from a private reseller. The land type determines who is allowed to access this region, how many avatars are able to access it simultaneously and how many objects can be created within this region. The objects in the world as well as the accessories for avatars are created via a powerful in-world object editor. The majority of the objects are created by the users themselves and every item in the world is an object. This ranges from large structures such as buildings to environment objects such as trees to interior objects such as tables. The objects are either created for personal use, to contribute them to the public spaces or to sell them on the marketplace.

[16]http://secondlife.com (last accessed 02.05.2010)
[17]http://lindenlab.com/ (last accessed 10.05.2010)
[18]http://secondlife.com/statistics/economy-data.php (last accessed 20.04.2010)
[19]http://www.businessweek.com/magazine/content/06_18/b3982001.htm (last accessed 02.05.2010)

User Participation and Appearance

In order for users to participate in Second Life, they have to install a client program on their computer: the Second Life Viewer. The viewer is available for all major operating systems (Windows, MacOSX and Linux) and can easily be installed with the help of a wizard. The viewer is used to connect to the Second Life servers and to display the 3D Virtual World. An user account must be created in order to be able to log into the world. The avatar naming in Second Life is quite unique and different from most other 3D Virtual Worlds. An avatar name is composed of a first name and a second name. The user is only able to create a custom first name, while the second name has to be chosen out of a list of pre-defined names. Upon the first login, the user is spawned in the welcome area where she can learn about the environment and experiment with the different features. Often there are more experienced users present in the welcome area who help newcomers and answer their questions.

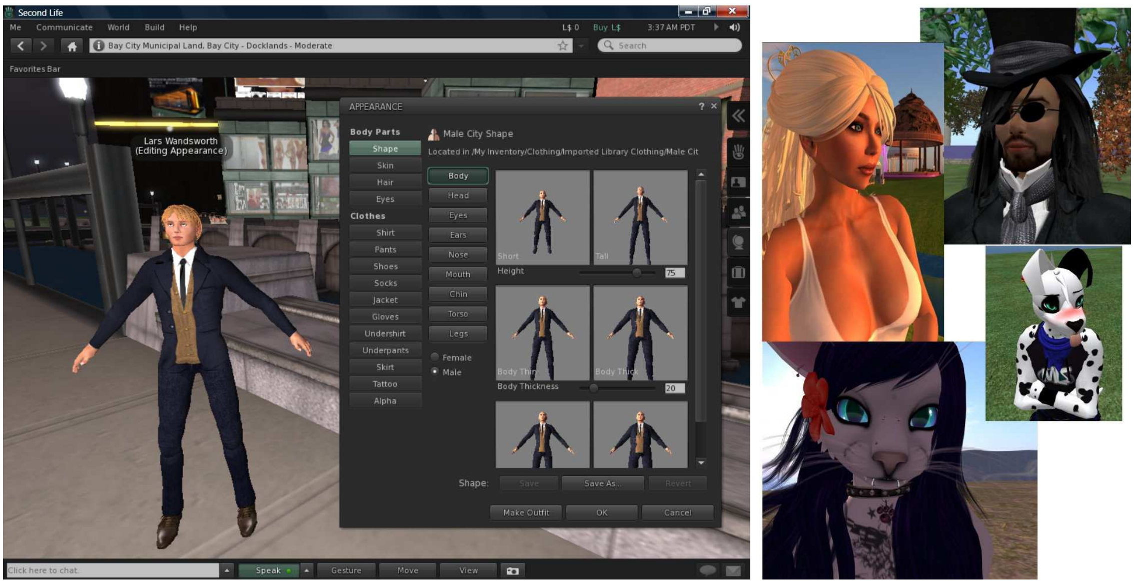

Figure 2.1: Customizing the avatar in Second Life and different examples of avatar styles.

The appearance of the avatar is an important status symbol inside the world and can be modified with the avatar editor. The Second Life viewer and the avatar editor are shown in Figure 2.1. It can be seen that nearly every aspect of the avatar is customizable. The modification functions are grouped according to the four body parts (shape, skin, hair and eyes) and the different types of clothes that can be worn (ranging from shirt to skirt to socks). In Figure 2.1, the shape of the body is currently selected. The height, the body thickness and the body fat can be altered by dragging the respective horizontal slider. For example, when the height slider is dragged to the left, the avatar will shrink and when the slider is dragged to the right the avatar will grow. Whenever an attribute is changed, the appearance of the avatar is instantly updated and the change is directly perceived by the user.

On the right side of Figure 2.1 several avatars are shown in order to illustrate the diversity of avatar styles. There is a female avatar that represents the ideal of beauty in the Western world. Then there is a male avatar with an elaborate, groom like, outfit. And there are two non-human, but animal like avatars. These animal avatars are referred to as “furries” and they are a cult of their own. Furries are not specific to Second Life, but they exist across different 3D Virtual Worlds. There are even exclusive furry groups and events in which only furries are allowed to participate.

Object creation

The creation of objects by the users is facilitated through a powerful in-world object editor that allows every user to create new content. The editor can be launched directly via the main interface and opens up inside the world. The editor mode enables the selection of existing objects which can then be modified and allows users to create completely new objects. The object editor is shown in Figure 2.2. In this Figure, the avatar Lars Wandsworth models a new car and the steering wheel of the car is currently selected. Auxiliary interface elements are overlaid over the steering wheel which enable the movement of the wheel along all three axes. The editor panel is shown on the left side of Figure 2.2. There are different parameters through which the appearance of the object can be modified. The steering wheel is based on the torus object type and among parameters that are adjustable for all objects (e.g. position, size, rotation) there are also parameters that are specific to the torus object type (e.g. hole size or radius). Furthermore it is possible to define textures, animations and gestures for a given object. When the editor mode is active, the viewport is not frozen and the user is still able to walk around with the avatar. The avatar can be positioned to the most advantageous modeling viewpoint.

The area on which the avatar is standing defines the object creation policy. The land owner is able to define which users or user groups are allowed to create and modify objects on a specific land area. The object creator, in turn, is also able to define who is allowed to modify the object and whether it is possible to clone and copy the object.

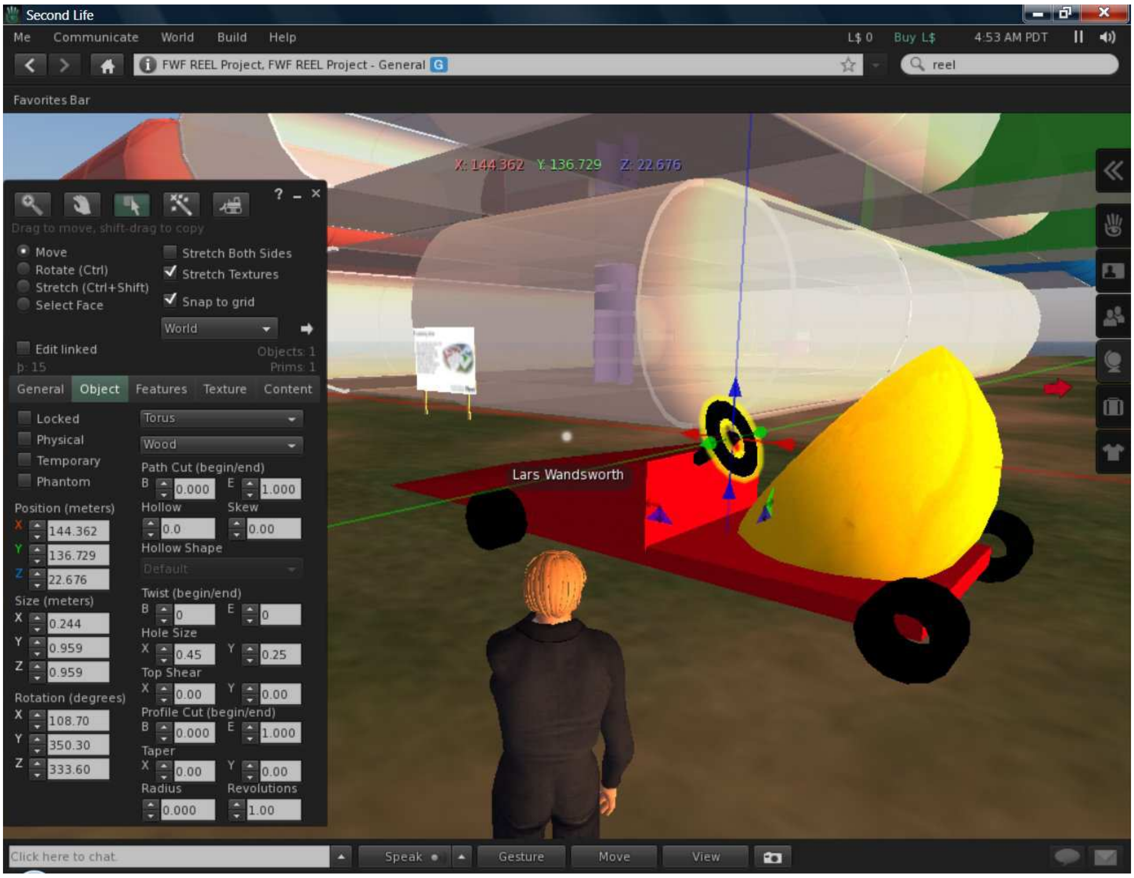

Figure 2.2: Object creation in Second Life.

Active Worlds

Active Worlds[20] is one of the oldest online 3D Virtual Worlds and was started in 1995 by Active Worlds Inc. The goal of Active Worlds is to create a 3D version of the Internet and to develop a pendant to a web browser. The virtual world is accessed through the Active Worlds Browser which is a client application that integrates a 3D view with an Internet browser. The client is illustrated in Figure 2.3 showing the 3D view on the left side and an opened browser window on the right side. Moreover, Active Worlds is not a single 3D Virtual World, but rather a platform for creating custom 3D Virtual Worlds. Every user is able to create a custom world which is either self-hosted or hosted by Active Worlds Inc. Depending on the world size, Active Worlds Inc. charges a setup and annual fee which forms a major source of income for the company. The universe consists of over one thousand virtual worlds that are hosted by Active Worlds Inc. and which are accessible to all citizens (more on that below). The most popular and most active world is called Alpha World which is in existence since 1995.

[20]http://www.activeworlds.com (last accessed 02.05.2010)

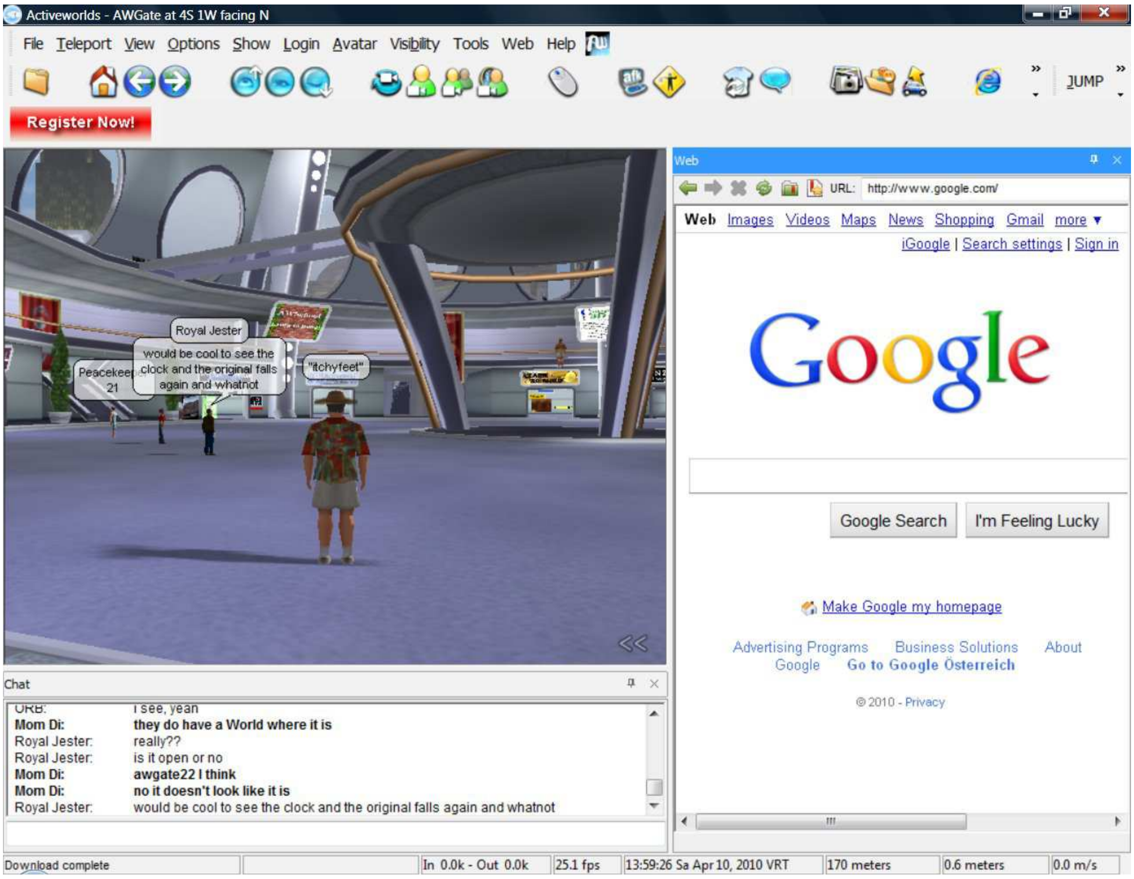

Figure 2.3: The welcome area in Active Worlds.

Active Worlds distinguishes between three different types of users: tourists, citizens and world owners. Tourists are users that participate in the world for free. They are less privileged than citizens and world owners. Among other restrictions, a tourist can only chose between two types of avatars, is restricted to buildings and worlds that provide tourist access and cannot create a unique avatar name. In order to enjoy additional benefits, a user has to pay a monthly subscription fee to become a citizen. Citizens can access all the features of the Active Worlds browser which include contact lists, cooperative building and the creation of autonomous bots. A world owner is a citizen who owns a world and is able to specify the properties and access policy for this world.

The community and content creation is an important facet of Active Worlds as well. The content in all the worlds was created by the users and according to information in Alpha World, this world alone comprised 221 million user created objects as of April 2010. While the objects in the world are stored in a proprietary format as Renderware scripts, objects can be imported from a wide variety of 3D modeling applications. Additionally, they can be created directly in the world as well. In terms of the community size, the last available numbers are from 2005. Back then the community had two million individual users and 70,000 registered citizens who were paying a monthly fee. It seems that the community has decreased in size since then, as the official Active Worlds forum only lists around 120 active members[21] (out of over fifty thousand registered members) and in our latest research sessions in Active Worlds during April 2010, only some ten to forty users were present in all the available worlds that are listed in the browser.

IMVU

IMVU[22] is a dedicated chat 3D Virtual World in which all activities revolve around chatting and socializing with other users. As of April 2010, IMVU has a user base of 40 million users with 6 million unique monthly visitors[23]. The virtual world of IMVU is composed of 3D chat rooms which are small sized 3D spaces with a maximum number of ten users per room. A room has a certain theme and is not restricted to a physical room, but can encompass outdoor areas as well. Examples of chat rooms are cafes, paradise islands or clubs. Users are able to create custom chat rooms and, similar to Second Life and Active Worlds, objects can be created by the users as well. In contrast to these worlds, IMVU does not provide an in-world object editor. The objects have to be created with 3ds Max[24], a third party 3D modeling software. The created objects are imported into IMUV and can be sold on the IMVU marketplace. The currency of the marketplace are so called “credits” which can directly be purchased from IMVU. The sale of these credits is the major source of income for IMVU. These credits cannot directly be changed back to real world money via IMVU, but there exist third party resellers that exchange credits into real world currency such as US$.

Avatar Home and Movement

The virtual world of IMVU is accessed via a dedicated client which has to be installed on the user’s computer. The interface of this client is shown in Figure 2.4. The tab like structure at the top of the interface is reminiscent of the tabs in a web browser. The tabs represent the different opened control panels and chat rooms in which the user is currently participating. It is possible to participate in multiple chat rooms simultaneously and the view can be changed to a different chat room by clicking on the respective tab.

[21] http://forums.activeworlds.com/ (last accessed 02.05.2010)
[22] http://www.imvu.com (last accessed 02.05.2010)
[23] http://www.imvu.com/about/index.php (last accessed 02.05.2010)
[24] http://usa.autodesk.com/adsk/servlet/pc/index?id=13567410&siteID=123112 (last accessed 02.05.2010)

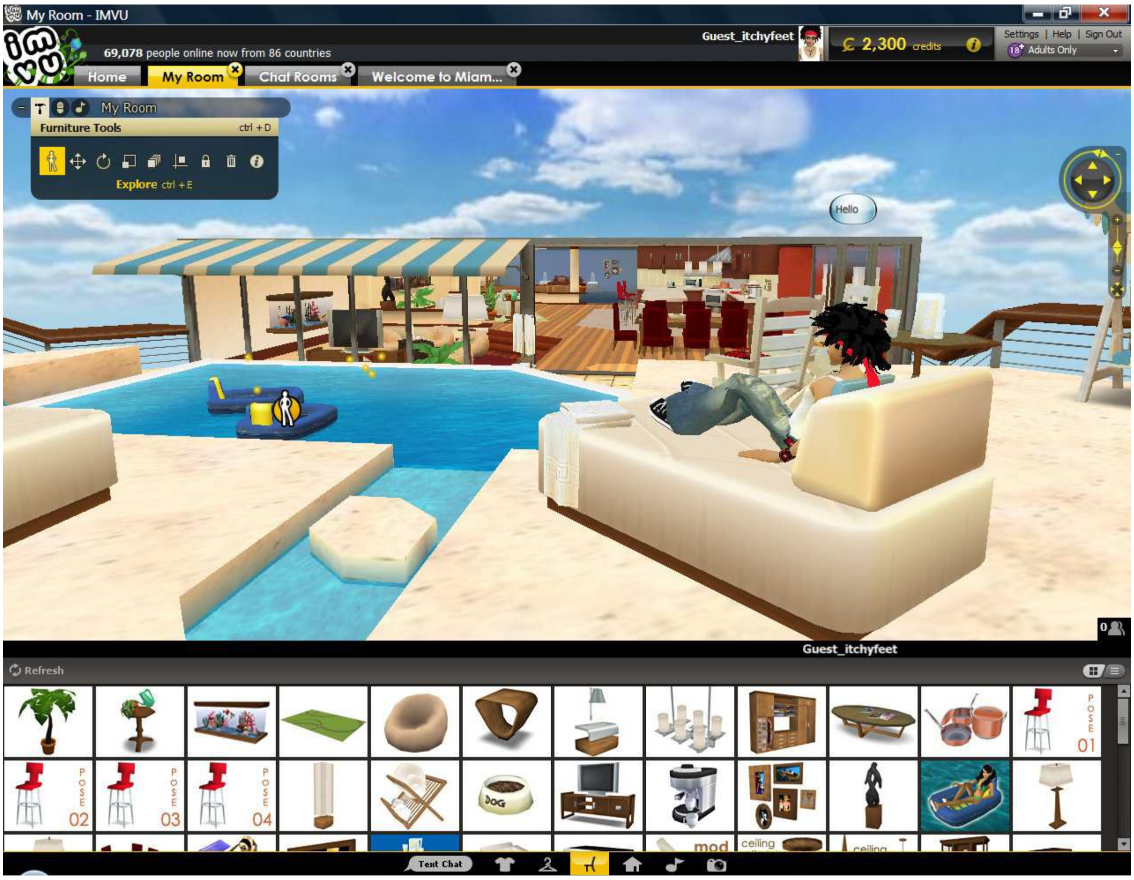

Figure 2.4: The IMVU interface.

A concept that is not found in this form in the previously presented worlds, is the notion of a home place for the avatar. In IMVU every user owns a luxurious apartment which can be furnished by the user. Such an apartment is shown in Figure 2.4 and referred to as “My Room”. The standard apartment already looks quite extravagant with a huge terrace, a swimming pool and nicely designed furniture. The apartment can further be customized by purchasing new furniture and re-arranging the objects in the apartment. The furniture catalog is displayed at the bottom of Figure 2.4 and the items can be purchased in exchange for credits.

The movement in IMVU is restricted to fixed positions in the 3D space and the user is not able to walk around with the avatar. In Figure 2.4 we can see that the avatar is currently sitting on a sofa in front of the swimming pool. When the user wants to change the location of the avatar, she can move the mouse cursor around in the virtual space and possible positions that are nearby the mouse cursor are displayed as yellow dots. This is illustrated through the swimming pool in Figure 2.4. The yellow dots indicate the positions to which the avatar can be teleported. The human icon with the yellow circle represents the currently selected location and when the user presses the left mouse button the avatar is teleported to the float in the swimming pool. The body posture of the avatar is determined by the chosen location. For example, at certain positions the avatar is standing, while at other positions the avatar is sitting. In Figure 2.4 it is possible for the avatar to sit at different places on the sofa. In the current position the avatar is lying, but there are other positions on the sofa that enable the avatar to sit on the edge or back of the sofa.

Meet-Me

The 3D Virtual World of Meet-Me[25] is a one-to-one replication of the real world Tokio which is developed by Co-Core Inc.[26] The real world Tokio was mapped into a virtual space based on the map data of car navigation software. As a result, the world encompasses a huge area with hundreds of suburbs where one can get lost easily. The connection to the real world Tokio is not only limited to the geographical aspects, but the weather, the seasons and the time of the day are also synchronized with the real world. Hence, the world is more of a simulation than an independent 3D universe. The simulation even includes the transportation facilities. Teleportation is not supported in Meet-Me and, besides walking, one can only get around by car or public transport. The 3D Virtual World of Meet-Me including a bus station is illustrated in Figure 2.5. The public transport encompasses buses and trains and like in the real world the user can only travel from one station to another station on the same bus or train line. The user might be required to change busses and/or trains to get to the destination. There is no travel time imposed when going from one station to another and the avatar instantly appears at the selected station. While busses are free of charge, a fee has to be paid when using the trains. When using the car, the user can travel from one parking spot to another parking spot.

Another interesting facet of Meet-Me is the language barrier that is imposed by this 3D Virtual World. The world and any additional resources such as the web site are available in Japanese only. It is therefore nearly impossible for non-Japanese speakers to participate in the world. Additionally, the approach to re-create a real world location is also different from the previously presented worlds. This can best be illustrated by comparing Meet-Me with IMVU. Similar to IMVU, Meet-Me also includes the concept of an avatar home which can be personalized by the user. While in IMVU the default avatar home is an extravagant, already furnished, penthouse apartment (cf. Figure 2.4), the default avatar home in Meet-Me is kept simple. In Figure 2.6 the default avatar home

[25]http://www.meet-me.co.jpg (last accessed 02.05.2010)
[26]http://www.co-core.co.jp (last accessed 02.05.2010)

Figure 2.5: Standing at a bus station in the Meet-Me 3D Virtual World

of Meet-Me is illustrated. The home consists of a small room that is not furnished and is reminiscent of the limited space in real world Tokio. The design of this room and the differences to the avatar home in IMVU illustrate the different world philosophies. IMVU tries to create an imaginary perfect world where every user is the owner of a luxury apartment, while Meet-Me tries to re-create the same conditions that are found in the real world.

The language barrier in Meet-Me has a great influence on the user population that can be reached and it was difficult to obtain information on Meet-Me during our research. According to the only official document in English that we have found[27], the goals in 2007 were to establish a community with one million users by the end of 2008 and to make the world accessible in other languages as well. In a personal communication with the Co-Core cooperation in April 2010, we found out that Meet-Me is still available in Japanese only and that support for other languages might be added in the future.

Papermint

The last example of a 3D Virtual World is an experimental and innovative 3D environment that is graphically based on 2D paper models in a 3D space and introduces a wide

[27] http://www.trans-cosmos.co.jp/english/company/news/pdf/2007/release070605e.pdf (last accessed 02.05.2010)

Figure 2.6: The avatar home in Meet-Me.

range of creative concepts. This world is called Papermint[28] and is developed by Avaloop[29]. The design of the world is different from what we saw in the previous worlds. The objects in Papermint are 2D paper models that are integrated within a 3D space. Figure 2.7 illustrates what such a design looks like. The avatar is standing in the middle of the screen inside a flower bed. There is a bench and a garden behind the avatar and the skybox is composed of surrealistic graphics. The controls in the open space are different from other 3D Virtual Worlds. The camera cannot turn around the axis in the open space and the view is fixed to a given direction. When the avatar moves to the left and right, the camera moves in parallel to the left and right respectively. When the avatar moves away from the screen, the camera follows the avatar and when the avatar moves towards the screen, the camera moves backwards. Inside the buildings the camera can turn around the axis. Similar to the third person view in other 3D Virtual Worlds, the camera is positioned behind the avatar and follows the movement of the avatar.

The landscape of Papermint is composed of mainland and water. The world is small in size when compared to the previous 3D Virtual Worlds and one can get from one end of the world to the other within several minutes. Teleportation is not supported and the avatar has to cover the distance to the target location by moving on the ground. On the mainland the avatar moves by walking, but as soon as the avatar approaches water, the

[28]http://www.papermint.com (last accessed 02.05.2010)
[29]http://www.avaloop.com (last accessed 02.05.2010)

Figure 2.7: The Papermint 3D Virtual World.

avatar jumps into it, changes into a paper ship and can sail across the water. In a future version, the avatar will be able to change into a paper plane enabling the exploration of the world from a bird's eye view.

The monetary system comprises two different currencies: paper coins and mint. While paper coins are purchased for real world money, mint is a type of plant that grows in the world and can be collected by the avatars. Both currencies can be used to buy items or to pay for services in the world, but mint exhibits certain restrictions: there is an exchange rate of two-to-one between mint and paper coins, mint is quite rare and can only be found occasionally and mint deceases over time - it only exists for 24 hours.

The community and the development of a social profile within the world are an important facet of Papermint. A concise representation of the user's profile is shown above the avatar. The profile captures the personal preferences of the user and lists the achievements of the user. The social status within the community is captured along five values: exploration, achievements, creativity, popularity and social activity. The latter two are influenced by the interaction with other users, the creativity is related to the design of custom clothes, the achievements are influenced by the number of in-world games that have been won and the exploration value captures the number of places that have already been explored. Furthermore, users can marry each other within Papermint, they can have babies together and they can adopt a certain profession. The professions include the court counselor who is capable of arranging marriages between users, the judge who is responsible for the social order and is allowed to punish users by disabling their communication facilities, the gatherer who collects plants which are later used by the designer who extracts colors from these plants and uses the colors to create new clothes.

This colorization process is based on game-like characteristics and quite specific to Papermint. While in Second Life an object can simply be colored by selecting the respective color from a palette, in Papermint the colors have to be extracted from plants. We are now going to present this color extraction process in more detail in order to illustrate the innovative nature of Papermint. A plant has between two and six colors. In order to extract these colors, one has to collect a certain number of these plants. The collection of a plant is based on a game-like process that requires certain control skills. When a plant is clicked with the mouse, two to six leaves are catapulted into the air which then steadily float to the ground. The leaves are numbered from one to six respectively and the user has to click the leaves in ascending order before they hit the ground. When a leave hits the ground, it disappears and it is no longer possible to collect this plant. Only when all leaves have been clicked in the correct order, the plant is considered collected and moved into the basket of the user. It is necessary to collect six plants of the same type to be able to extract the colors from these plants. The colors can then either be extracted with a machine in a design studio or via a flower pot in the apartment of the avatar. In the latter case the extraction process is free of charge, but it takes a certain amount of time until the colors are extracted. The color extraction with a machine costs a certain amount of paper coins or mint. However, in this case the colors become instantly available. The colors are stored on a color palette in the user's inventory. These color palettes can then be traded with other users, they can be used to color ones clothes and they can be sold to the "Dealer" in exchange for mint. Additionally, the color extraction can help to increase the wealth and the social status of a user within the community. Although this colorization process is quite elaborate, it probably has the goal to engage users in the world through the game-like collection process and should help users in establishing a social profile within the world.

2.3 Application Development in 3D Virtual Worlds

The application development in 3D Virtual Worlds can take different forms which are dependent on the characteristics of the chosen world. We therefore make a high level distinction along two dimensions which deal with the location where the application is developed and the maturity of the development environment.

- **Location:** Integrated in third party 3D Virtual World vs. Dedicated 3D Virtual

World

- **Maturity:** 3D Virtual World Framework vs. 3D Technology

The first dimension, the location, defines where the application is developed, how it will be hosted and how it is accessed. The integration into an existing third party 3D Virtual World lies on the one side of the spectrum, while the provision of a custom and dedicated 3D Virtual World lies on the other side. In the latter case the application and the 3D Virtual World is hosted and operated by the application developer, while in the former case the 3D Virtual World is hosted and operated by a third party provider. Both approaches have their advantages and disadvantages.

In the case of integrating the application in an existing world, the technical infrastructure and the user base is already established. The application developer can directly profit from the aggregated know how, does not have to worry about uptime and hosting issues and furthermore has access to a wide range of potential users. The provision of the technical infrastructure has the downside that the development is constrained by the technical limitations that are imposed by the 3D Virtual World. Additionally, the hosting of the application by a third party has the disadvantage that the accessibility and availability of the world depends on the provider. The provider may chose to discontinue the 3D Virtual World from one day to another and may also block access to the application. These disadvantages can be circumvented through the self-hosting of the 3D Virtual World. In this case the developers have complete control on the accessibility and are able to customize and adapt the 3D Virtual World to their needs. The disadvantage in this case is the missing user base. It might therefore be more difficult to attract and motivate users for participation.

The decision about the target environment is dependent on the application that is developed. For example, in the Itchy Feet project where the goal was to create a research test bed and to conduct a study with a limited number of test users, the creation of a dedicated 3D Virtual World was more suitable. Due to the limited number of test subjects, the existence of a user base was not important and a dedicated 3D Virtual World provided us with more freedom for experimentation and custom adaptions. If we consider a different case in which a company wants to utilize a 3D Virtual World to advertise their products, the integration of the application into an existing 3D Virtual World will be more advantageous. The company will intend to reach as much customers as possible and the access to a broad range of people will be a crucial requirement. In an existing 3D Virtual World with an established user base it will be easier to attract customers than through the distribution of a new 3D Virtual World client.

When looking at the five previously discussed 3D Virtual Worlds from an application development perspective, we can see that the creation of custom applications is supported to a different degree. Second Life and Active Worlds are the most flexible. They both enable the creation of custom objects, the modeling of landscapes and provide a scripting language. Objects can either be created directly in the world or they can be imported from external formats. The program logic of the application can be specified via the scripting language and custom behaviors can be programmed into the world. IMVU does not offer a scripting language and developers are restricted to the creation of custom chat rooms and the creation of objects. The objects have to be created with external 3D modeling applications as IMVU does not offer an in-world object builder. From the application development point of view, Papermint and Meet-Me are the most restrictive worlds. In Papermint as well as in Meet-Me users are only able to create custom clothes and neither object modeling nor scripting are supported.

Dedicated 3D Virtual Worlds

A dedicated 3D Virtual World provides more flexibility for developing an application. The maturity in this case refers to the technical framework upon which the 3D Virtual World is realized. This can range from the highest level where a sophisticated 3D Virtual World framework is used to the lowest level where the whole environment is created from scratch upon a certain 3D technology. This relationship is best illustrated by example. OpenGL[30] is a low level 3D graphics library with an Application Programming Interface (API) that provides over 250 functions for drawing 2D and 3D graphics. The library is low level in the sense that only the drawing of graphics is supported, but no means for loading complex 3D objects or managing the scene graph are provided. These functionalities are then provided by libraries or frameworks that build upon OpenGL. One example for such a framework is the jMonkey Engine[31] which is a 3D engine for the development of 3D environments. Among a long list of features it includes a scene graph for managing 3D objects, provides support for the import of 3D objects from different formats and includes high level graphical effects. While jMonkey greatly facilitates the creation of a dedicated 3D Virtual World, there exists an even more specific 3D Virtual World framework that builds upon jMonkey. The Open Wonderland[32] toolkit uses jMonkey as the rendering engine and integrates additional functionalities that are useful for building 3D Virtual Worlds. These functionalities further ease the application development

[30]http://www.opengl.org/ (last accessed 02.05.2010)
[31]http://www.jmonkeyengine.com/ (last accessed 02.05.2010)
[32]http://www.openwonderland.org/ (last accessed 02.05.2010)

and include a client/server architecture, an avatar system and integrated communication facilities such as voice and text chat.

Again, the requirements of the application determine the technological foundation upon which the application should best be implemented. A 3D technology offers the greatest possible freedom, but also requires the greatest development effort - especially for functions that are readily available in 3D Virtual World frameworks. In most cases, an application will be build upon a more sophisticated framework that comes bundled with a set of useful features and functionalities. Examples of such frameworks include the above mentioned Open Wonderland, the Open Simulator[33] and the On-Line Interactive Virtual Environment (OLIVE)[34]. The Open Simulator is based on the same technological framework as Second Life and provides an infrastructure for the development of client/server based 3D Virtual Worlds. The same message protocols as in Second Life are used and it is therefore possible to create a client application with which the Second Life universe can be accessed. While Open Wonderland and the Open Simulator are community driven open source projects, OLIVE is a commercial product developed by Forterra Inc. It is targeted at enterprises for the creation of collaborative 3D environments in which meetings are conducted, events are organized or trainings are performed. Similar to Active Worlds, Forterra Inc. offers a hosting service. The created worlds can either be hosted by Forterra Inc. or they can be deployed and operated by the enterprises themselves.

Another type of framework that can be utilized for the development of 3D Virtual Worlds are 3D game engines. A 3D game engine provides a supporting framework for the creation of 3D computer games. While the primary application domain are computer games, they can typically be employed for the creation of 3D Virtual Worlds in other domains as well. The functions and tools that are provided by these engines overlap with the requirements for building 3D Virtual World applications. 3D game engines have been used in the industry[35] and in research for the creation of 3D Virtual Worlds (Chao, 2001; Kot et al., 2005; Moloney et al., 2003). There exists a huge variety of different 3D game engines ranging from free of charge open source engines[36,37] to state-of-the art commercial engines for which licensing fees have to be paid[38,39]. A comprehensive database which lists most available game engines can be found on the game development website

[33]http://opensimulator.org/ (last accessed 02.05.2010)

[34]http://www.forterrainc.com/ (last accessed 02.05.2010)

[35]http://www.secretlair.com/index.php?/clickableculture/entry/ibm_rolls_its_own_virtual_world/ (last accessed 02.05.2010)

[36]http://irrlicht.sourceforge.net/ (last accessed 02.05.2010)

[37]http://www.ogre3d.org/ (last accessed 02.05.2010)

[38]http://www.unrealtechnology.com/technology.php (last accessed 02.05.2010)

[39]http://mycryengine.com/ (last accessed 02.05.2010)

DevMaster.net[40]. Since we have utilized a 3D game engine - the Torque game engine - in our work, we are now providing an introduction to this engine. This introduction illustrates the features that are provided by this engine and should help in developing an understanding for the required features of 3D Virtual World development.

The Torque Game Engine

The Torque game engine is an open source game engine developed by GarageGames[41]. The feature list includes seamless indoor/outdoor rendering, animation support, a lighting engine, powerful editors, a scripting language and network functionality. Furthermore the royalty free licensing model allows developers to distribute and publish their games without further costs. The Torque game engine offers several editors and tools for the creation of games and 3D Virtual Worlds. These editors range from a world editor, used to arrange objects in the 3D Virtual World, to a terrain editor, used for the creation of the terrain, to a graphical user interface (GUI) editor, used for the design of the heads-up-display and 2D interface elements. The behavior of objects and the game logic is programmed via the scripting language. If the scripting language is not applicable (due to functional or speed limitations), it is possible to alter the game engine itself. The code is written in C++ and is directly compiled into the game engine executable.

Torque is an industry-proven game engine and has been used in numerous commercial and independent games. In the scientific world the Torque game engine has been utilized for research projects as well. Moloney et al. (2003) developed a design critique tool with the Torque game engine and IBM is using it for an internal research project on virtual worlds[42]. Moreover, the engine is widely used in education for teaching the principles of 3D game engines. The GarageGames web site lists more than 200 schools and universities that use the Torque game engine in their class rooms.

2.4 3D Virtual Worlds Research

This Section will provide a general overview on research in 3D Virtual Worlds and illustrate different types of research efforts that have been conducted with or within 3D Virtual Worlds. The related work that is specific to the individual Chapters will then be discussed in the Background Sections (3.1, 4.2 and 5.1) of the respective Chapters.

[40] http://www.devmaster.net/engines/ (last accessed 02.05.2010)
[41] http://www.garagegames.com (last accessed 02.05.2010)
[42] http://www.secretlair.com/index.php?/clickableculture/entry/ibm_rolls_its_own_virtual_world/ (last accessed 02.05.2010)

Jäkälä and Pekkola (2007) reviewed the past 15 years of research on 3D Virtual Worlds and found that the research during the 90s was focused on technological themes. The technological possibilities were explored and different types of hardware devices (Pastoor and Wöpking, 1997) such as the responsive workbench (Krüger and Fröhlich, 1994) or the CAVE (Cave Automatic Virtual Environment) (Cruz-Neira et al., 1993) were created. The research mostly focused on immersing the user through technology and desktop based 3D Virtual Worlds, as we have defined them previously, did not receive much attention in research. However, a commercial game version of 3D Virtual Worlds that were rather based on software than hardware and focused on communities rather than individuals started to emerge during this time (Castronova, 2005, p. 285). These Massively Multi-User Online Role Playing Games were the first 3D Virtual Worlds that motivated researchers to study the social space within these environments. Castronova (2001) was one of the first researchers to study the economics that emerge within MMORPGs. He studied the virtual world of Norrath in the MMORPG EverQuest and conducted an economics survey (the Norrath Economic Survey (NES)) in which more than 3,000 players participated. The results showed that people spend a great portion of their spare time in the world (average of 4.7 hours per day) and that they partly identify themselves with the world to a strong degree (20% agreed that they "live in Norrath but travel outside of it regularly"). Furthermore, the accumulated virtual items of every user have a high real world economic value. The virtual currency can be exchanged to real world money on (illegal) exchange markets and based on these exchange rates, the average value of a player's virtual items is equal to 2,000 US$. Based on these exchange rates and avatar prices on avatar auction markets, the author calculated the Gross National Product (GNP) of Norrath. According to his calculations Norrath has a GNP of 135 million US$ making it the 77th richest country in the real world. In subsequent works, Castronova further explored the economies, markets and property values in MMORPGs (Castronova, 2003, 2005). Other researchers that studied the value of virtual goods are Lastowka and Hunter (2004) who also examined the legal rights concerning virtual goods and Malaby (2006) who bases the value in 3D Virtual Worlds on three cornerstones: market capital, social capital and cultural capital.

The psychology and motivational factors of MMORPG players and 3D Virtual World users have been studied as well. The research of Griffiths et al. (2003) also focused on players of EverQuest. They gathered demographic data in two online surveys and found out that the stereotype of players being adolescent students does not hold true. According to their data, over 60% of the respondents were older than 19 years. Yee (2006) conducted a longitudinal demographic and motivational study on MMORGP players. The study period lasted three years and during several survey periods data from over 30,000 respondents was collected. Similar to Griffiths et al. (2003), he found that MMORPGs attract people from all ages and genders. For example, half of the respondents work full time, over one third is married and more than twenty percent have children. Based on the collected data he derived a motivational framework consisting of five factors: achievement, relationship, immersion, escapism and manipulation. The data showed that male players were stronger motivated by the achievement and manipulation factors, while for female players the relationship was a stronger motivational factor. The social interactions between MMORPG players were studied by Cole and Griffiths (2007). Similar to the previous works, they collected data via surveys and found out that MMORPGs are highly social places. The social component forms an essential element of the overall game experience and friendships as well as long-term relationships can emerge when playing those games.

Chesney et al. (2009) showed how social 3D Virtual Worlds can effectively be used for performing in-world experiments. They conducted five economic experiments in Second Life to assess the feasibility of experimentation in 3D Virtual Worlds and to find out whether the results differ from those found in standard laboratory settings. Special attention was paid to methodological concerns in terms of test subject representativeness. After the experiments the ideals of the test subjects were elicited via a human values questionnaire. The results were compared to a study on human values that had collected data from several European countries with 1,500 samples from each country. They found that the human values of Second Life residents differ from this study to the same extent as those of a standard UK student sample. Since test subjects are frequently drawn from the student population, Second Life residents can therefore provide a sample pool with a comparable validity. In terms of the economic experiments they also found no significant differences to the result in traditional experiment settings. They conclude that 3D Virtual Worlds might be a possible alternative for the conduction of certain types of experiments and that many standard experiments could be recreated cheaply and effectively within 3D Virtual Worlds. However, due to certain disadvantages (less control, different population, technological barriers) they are not suited for every type of experiment. For example, an experiment that would investigate a physical condition on a specific population is not suited to be designed as a virtual experiment.

Game Engines used in Research

As discussed in the previous Section, 3D game engines also prove suitable for the creation of 3D Virtual Worlds and they have been used in different research projects to create

3D Virtual Worlds. One of the first examples was PSDoom by Chao (2001). In this work the Doom game engine is used as an interface for the management of Unix system processes where each process is represented as a creature. Shooting the creature causes the corresponding process to "die". The intention of this work is to explore new interface metaphors that provide a more intuitive access to computers for computer illiterate people. Moloney et al. (2003) developed an immersive design critique tool for architects. They use an open source game engine to create a collaborative virtual environment enabling students to create 3D architectural models. The environment allows students to iteratively alter the model and to directly perceive these changes. Moreover, reviewers are able to attach comments to the architectural elements in the world and the design can be discussed collaboratively inside the world. In the context of information visualization Kot et al. (2005) use a 3D game engine to facilitate the comprehension of source code. The environment enables software developers to quickly perceive the structure of the source code and the relationship between different source code files. To this end, source code files are visualized as 3D objects in the 3D Virtual World. The user can explore the structure and relationship of the different files by walking through the environment. When the user walks into a file object, the content of this file is displayed on the screen. The environment can be explored by multiple users simultaneously and it is possible to conduct guided tours in order to introduce new developers to the structure of a code base.

3D Virtual Worlds and Virtual Reality

In the Introduction to this Chapter we already discussed the ambiguity of the term 3D Virtual World and established our definition of 3D Virtual Worlds. The same holds true for the Virtual Reality domain where the term 3D Virtual World or Virtual Environment might refer to a fully immersive CAVE (Cave Automatic Virtual Environment) (Cruz-Neira et al., 1993) in one instance, while in other instances the term refers to a 3D world generated on a desktop computer. Blade and Padgett (2002) also observed that the term Virtual Environment is used by authors to fit the technology they are working with. The authors present an attempt to establish a common terminology by submitting a standard proposal on Virtual Environment terminology to the IEEE Standards Association. However, according to the IEEE web site, the proposal was withdrawn and is no longer endorsed. In the following we are going to highlight the differences and similarities between our definition of 3D Virtual Worlds and Virtual Reality applications.

In this thesis the term 3D Virtual World refers to a 3D world generated on a desktop computer controlled with keyboard and mouse. Barilleaux (2001, p. 8) refers to such a setup as POCS (Plain Old Computer System) highlighting the simplicity of the employed

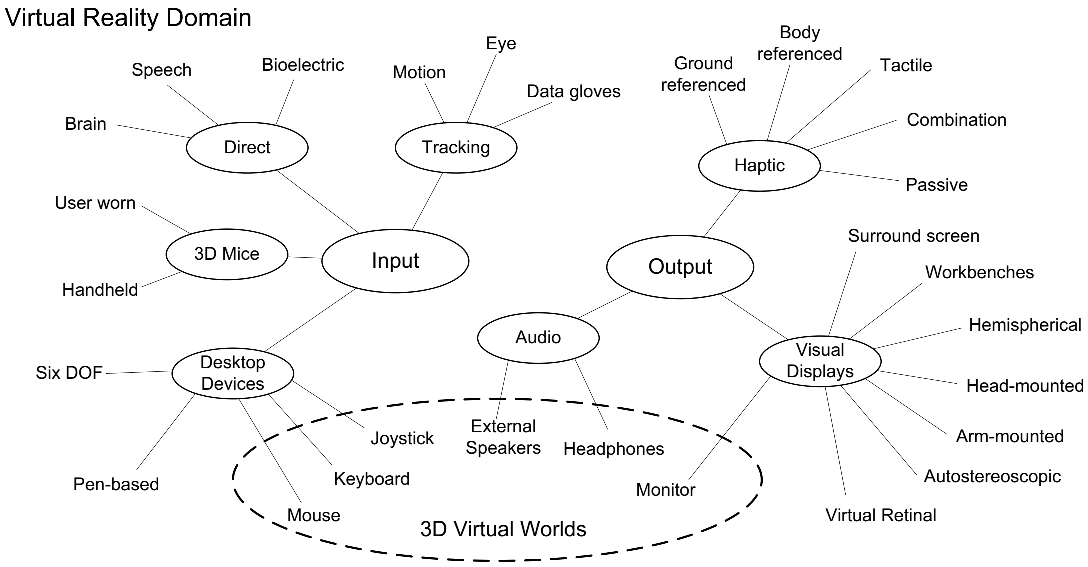

Figure 2.8: Classification of input/output technologies in the Virtual Reality domain according to Bowman et al. (2004), including our definition of 3D Virtual Worlds.

hardware devices as opposed to the diversity of complex technical devices found in the Virtual Reality domain. Still, from a technological point of view this definition of 3D Virtual Worlds encompasses a small subdomain in the overall domain of Virtual Reality. This is illustrated in Figure 2.8. In Virtual Reality research the setup of a 3D world on a desktop computer is often considered as a special case. Setups that rely on a standard monitor as output, but with possibly more sophisticated input devices than keyboard and mouse, are referred to as “Fish Tank VR” (Arthur et al., 1993). This naming emphasizes the fact that the user is observing the environment from the outside rather than being a part of the environment. Focus is rather laid on immersing the user through technological devices than immersing the user psychologically by creating a feeling of presence. The development of additional technical input and output devices such as head-mounted displays or virtual gloves for the creation of immersion is a central point in Virtual Reality research. Castronova (2005, p. 285) also argues that the game version of online 3D Virtual Worlds focuses on software, while the game version of Virtual Reality applications focuses on hardware.

The results of hardware focused research in Virtual Reality are usually specific to a certain technology and are not applicable to 3D Virtual Worlds. However, there also exist research works in the Virtual Reality domain that do not make assumptions on the employed hardware and which can be applied to 3D environments in general, including 3D Virtual Worlds. The focus of such works is on general three dimensional characteristics that are not influenced by the hardware. This includes, for example, selection, manipulation and travel techniques, but also usability guidelines and evaluation methodologies. For example, while the book of Bowman et al. (2004) on 3D User Interfaces is placed in the Virtual Reality domain and has a focus on technical devices, the authors also state that "the principles and guidelines we provide are usually applicable to any 3D UI" (p. 26). This implies that certain research findings of the Virtual Reality domain are applicable to 3D Virtual Worlds, if the differences are kept in mind. This is best illustrated by the usability evaluation catalog MAUVE (Multi Criteria Assessment of Usability for Virtual Environments) presented by Stanney et al. (2003). They created a taxonomy of usability criteria that are relevant for Virtual Reality applications. On the highest level the taxonomy distinguishes between system interface and user interface criteria. While the elements of the system interface group also apply to 3D Virtual Worlds (e.g. navigation, object manipulation, visual output), the user interface group includes criteria that are less relevant to 3D Virtual Worlds. This includes criteria such as sickness or aftereffects which can be neglected for 3D Virtual Worlds. In the remainder of this thesis we will utilize techniques and research results that were established in the area of Virtual Reality and will apply them to 3D Virtual Worlds.

2.5 Summary

In this Chapter we provided a definition of 3D Virtual Worlds and presented the features and characteristics of different 3D Virtual Worlds through several examples. Second Life was presented as one of the most mature environments in terms of movement, object creation and interaction. Active Worlds exemplified the concept of a 3D browser and showed how a universe of multiple 3D Virtual Worlds is created upon the Active Worlds platform. IMVU was used as an example of a 3D Virtual World that has a clear focus on chatting and furthermore employs limitations on the movement of the avatar. Meet-Me showcased the language barriers that can be inflicted by a 3D Virtual World and illustrated how an environment is designed for a specific target audience. Papermint was used to illustrate the creative potential of 3D Virtual Worlds and illustrated how it is possible to experiment with new ideas and concepts.

The building of applications in 3D Virtual Worlds was discussed and we distinguished between the integration of applications in existing 3D Virtual Worlds and the provision of applications through dedicated 3D Virtual Worlds. We highlighted the advantages and disadvantages of both approaches and presented game engines as a possible framework for creating dedicated 3D Virtual World applications. Finally, we provided an overview of related research works that deal with 3D Virtual Worlds and showed how research results from the Virtual Reality domain can be utilized for 3D Virtual Worlds as well.

CHAPTER 3

Engineering 3D Virtual World Applications

The development of software applications is a complex task and the outcome depends on a variety of parameters that are subject to change throughout the whole timeline of development. The constant delivery of high quality software is a demanding challenge that requires consolidated technological knowledge, previous experience as well as knowledge of management and planning. In Section 3.1 we provide an overview on the state-of-the-art development methods and review the emergence of software engineering methodologies. The process model of the Rational Unified Process is introduced and development methodologies in the Virtual Reality and 3D Virtual World domain are presented. Provided with this knowledge, the process model for engineering applications in 3D Virtual Worlds is proposed in Section 3.2. We show how we applied the general structure of the Rational Unified Process and identify the key disciplines that are required for building applications in these environments. Section 3.3 then illustrates how the process model emerged from the Itchy Feet project, how an initial version was used to create the 3D e-Tourism environment Itchy Feet and the cultural learning application ICURA and what lessons we learned in this process.

3.1 Background

Software Engineering Methodologies

The experiences that were gained during software development in the 1950s and 1960s, eventually led to the first process models which aimed to capture the different stages of software development in a well-defined and formal way. A model that received widespread attention during the 1970s and is also referred to as the "granddaddy of all lifecycle models" (McConnell, 1997, p. 136) is the waterfall model which was introduced by Royce (1970). In its most simple form, the development stages are carried out in a sequential order ranging from requirements, analysis, design, coding to testing. While Royce argues that this simple form can cause problems and he also proposes several strategies to enhance the simple model (iteration between stages, design first, involve users, two passes), the waterfall model was mostly adopted in its simple form. The sequential execution of the stages had the effect that problems were discovered late in the project during the testing stage and a considerable effort was required to adapt and change the software. This staged development in the waterfall process is often blamed as a source for failing software projects and Gilb (1985) notes that the "waterfall model may be unrealistic and dangerous to the primary objectives of the software project". He proposes an evolutionary model instead. But also Royce had stressed that the simple model had never worked on large software projects. To counteract the risks that are imposed by the basic process, he proposes five additional enhancements. The first is a preliminary program design stage that takes place before the analysis stage in order to get an understanding of the system that is being developed and to identify possible technical constraints at an early stage. The second enhancement deals with the documentation of the design. The documentation serves as the cornerstone for communicating the design and in Royce's opinion a strict and ruthless documentation policy should be enforced. As a third enhancement he suggests that the software should not be created in one pass, but in two passes. The creation of a pilot model allows the project manager to get a feeling for the required effort and the subsequent development can then better be estimated and planned. Testing is identified as the area that causes the greatest risk, since it occurs at the latest stage and consumes the largest number of resources. A thorough test planning, control and monitoring is therefore proposed as a fourth enhancement. The last enhancement includes the involvement of the customer throughout the whole project, in order to clarify misunderstandings and to develop a product that is up to the expectations of the customer.

According to Boehm (1986), the major shortcoming of the waterfall model is the emphasis on a complete documentation which requires that the requirements are fully documented after the early analysis already. He notes that this can work well for certain types of software applications where it is possible to capture the requirements in the beginning, but does not work well for interactive end-user applications where the requirements are only poorly understood upfront. As an alternative to document-driven processes like the waterfall process, Boehm proposes a risk-driven process that is based on a spiral model. The development is broken down into cycles in which the software product is incrementally developed. Each cycle of the spiral consists of three steps. In the first step the risk analysis is conducted by working out the objectives, searching for alternative approaches to realize the functionality and identifying the constraints imposed by these alternatives. In the next step the identified alternatives are evaluated against the objectives and possible sources of risk are identified. The activities in the third step depend on the remaining risks. In case there are performance or user-interface risks, a prototype is developed in an evolutionary fashion to address and resolve these risks. This prototype can then be elaborated in subsequent cycles until all these risks have been resolved. In case there are no performance or user-interface risks or the prototype development has already resolved these risks, the successive steps are similar to the stages in the waterfall model; but they are executed incrementally rather than sequentially. After each cycle a review of the last cycle is conducted and the next cycle is planned. The spiral model fundamentally shaped subsequent process models and it was an influential model to promote the idea of iterative and incremental software development.

The evolution of iterative and incremental development in software engineering is summarized in an article by Larman and Basili (2003). They trace the roots of this practice back to the 1930s during which a cyclic procedure for quality improvement called “plan-do-study-act (PDSA)” was proposed by Shewhart (1986). They present several examples of projects that already used an iterative approach in the 1950s, 1960s and 1970s. The paper showcases that the strict, sequential and document driven application of the waterfall process was identified as a source of problems by different authors. A possible reason for the prevalence of the waterfall model in the 1970s and 1980s might be found in the software standards of the US Department of Defense (DoD) which advocated a single pass waterfall model. In the late 1980s, after the DoD had experienced several difficulties with their software projects, the waterfall model was dropped and iterative and incremental methods were incorporated into their standards. In the 1990s iterative and incremental methods received widespread attention in the software engineering field and most state-of-the-art processes and methodologies exhibit an iterative nature.

The Rational Unified Process (RUP)

The Rational Unified Process (RUP) is a process framework whose origins date back to the 1990s and which was constantly refined and improved. It was developed by Rational Software until 2003 when Rational Software was acquired by IBM and is henceforth developed by IBM. What sets the RUP apart from other methodologies is the philosophy with which the RUP is created. The RUP is treated and developed in the same way as a software product. The process is constantly refined and updated by IBM and new versions are released in regular intervals. This software package encompasses a huge collection of process descriptions, templates and tools that support developers and managers throughout all phases of software development. The core component of this package is the method composer, a powerful editor which enables developers and managers to control and plan all aspects during development. The method composer is based on the Eclipse framework and a screenshot is shown in Figure 3.1. The selected configuration is shown on the left side. We can see that the classic configuration for large projects is selected. The different workflows, such as "Review the Architecture" or "Use-case Design", are grouped by discipline and can be selected to get guidance and support in conducting the respective workflow. The right side in Figure 3.1 shows the template for an artifact, namely the business case.

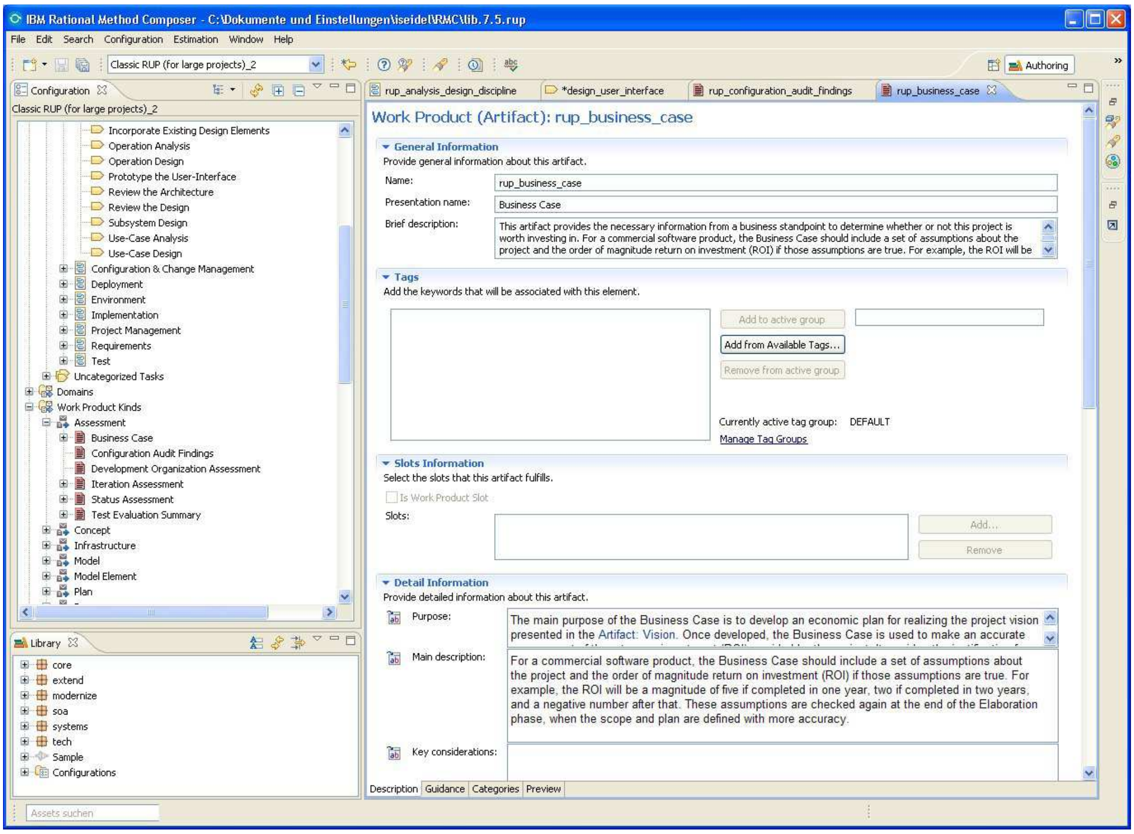

Figure 3.1: The RUP method composer.

While the RUP provides very fine grained and detailed descriptions of activities, we are more interested in the high level process model. The RUP is an iterative, use case driven and architecture centric process. It is iterative in the sense that the software is developed incrementally in multiple iterations, it is use-case driven in the sense that use-cases are the primary driving force for the specification of the requirements and it is architecture centric in the sense that the organization and structure of the software is described through an architecture description and the software is based on an architectural prototype.

The process is based on two dimensions: the static structure and the dynamic structure. The static structure describes what kind of activities are performed by which kind of roles in which way at what time. An activity is a unit of work that is performed by a certain role and usually involves the creation or update of an artifact. For example, the activity “Find use cases and actors” is performed by the system analyst during which the artifact “Use-case model” is created and updated. A workflow arranges multiple activities in sequences to define the interactions between different activities and roles. Activities and workflows are organized in project disciplines which are split in six engineering disciplines and three supporting disciplines. The engineering disciplines are: business modeling, requirements, analysis and design, implementation, test and deployment. The supporting disciplines are: configuration and change management, project management and environment. Figure 3.3 illustrates how these disciplines are organized along the iterative development cycle of the RUP.

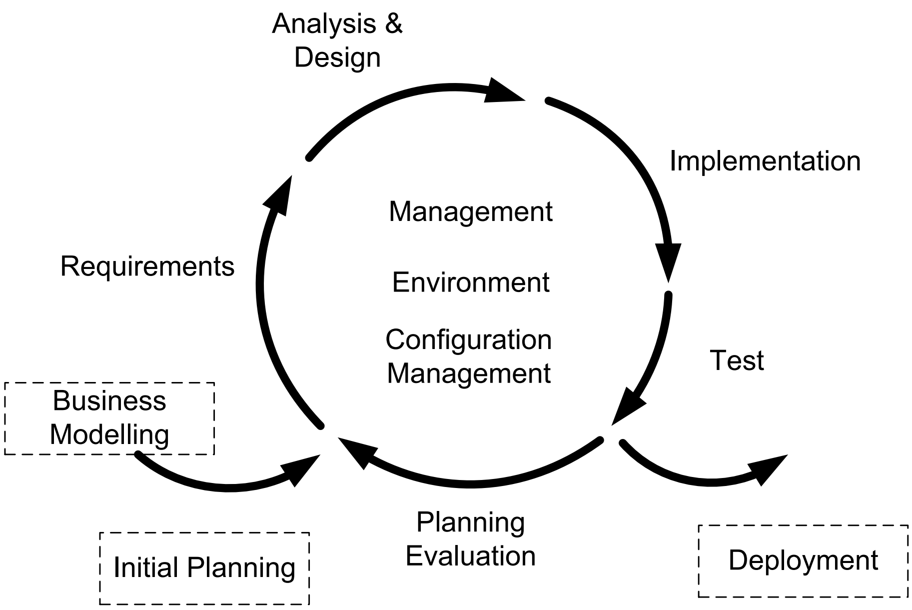

Figure 3.2: The iterative cycle of the RUP as presented by Kruchten (2006).

In the business modeling discipline the focus is on understanding the structure, workflows and problems in the target organization for which the software is developed. The goal is to understand the business processes and to identify the involved actors. Provided with this knowledge, the requirements for the system are established in the requirements discipline. They serve as the agreement between the stakeholders and the developers on what is being built and define the boundaries of the system. In the analysis and design discipline, the requirements are transformed into a system model that specifies the implementation of this system. According to the architecture centric nature of the RUP, the goal is to establish a robust architecture upon which the software is build. The implementation discipline deals with the actual realization of the software, including the organization and structure of the source code. The goal of the testing discipline is the validation of the software against the requirements. Test procedures and routines are specified to identify problems which are then documented and reported. The deployment discipline deals with setting up the software in the operation environment. This not only includes the packaging, distribution and installation, but also the training of end users and beta testing.

In terms of the supporting disciplines, the configuration and change management discipline is especially important in an iterative process. The artifacts are continuously updated in the iterative cycle and procedures for managing these changes must be established. Additionally, the organization and relationship of the source code components must be managed properly in order to be able to build the working software. The project management discipline contains activities for managing the project throughout the whole lifecycle of the development, for planning the iterations and for managing the risk. The environment discipline deals with the establishment of the work environment. The necessary tools for development are identified and the process itself is configured and improved to fit the settings in the work environment.

The dynamic structure describes how the process is executed and how the timeline of the project is organized. This encompasses four phases which are executed in an iterative fashion resulting in four milestones that are completed after each phase. The phases are: inception, elaboration, construction and transition. In the inception phase the vision and the project scope are established and the phase is concluded with the lifecycle objective milestone. The goal of the elaboration phase is the development of requirements and the creation of a robust architecture which is used as the basis for further development. The lifecycle architecture milestone concludes this phase. In the construction phase the software is incrementally constructed until the initial operational capability milestone is reached. The transition and deployment of the software in the target organization is then the goal in the transition phase. The lifecycle is concluded after this phase with the product release milestone. The phases differ in terms of their time span and resources that are consumed. A phase can span multiple iterations and typically the different phases are conducted within a different number of iterations. The relationship between the dynamic and the static structure is illustrated in Figure 3.3. We can see that the inception phase is conducted within one iteration, elaboration and transition phase take up two iterations and the construction phase encompasses the greatest number of iterations - three or more. The number of iterations is specific to a project and as part of the project management activities, the optimal number of iterations for the project is defined. Kruchten (2006, p. 133) states that "normal projects have 6 ± 3 iterations" and calls this the "six plus or minus three rule of thumb". Furthermore he distinguishes between three levels of iteration: low - three iterations (0, 1, 1, 1); typical - six iterations (1, 2, 2, 1); high - nine iterations (1, 3, 3, 2). Note that the possibility of having zero iterations in the inception phase does not mean that no activities are conducted in this phase. Kruchten argues that in many instances no software is produced during this phase and that planning and marketing activities do not account for a real iteration. However, since this definition of having zero iterations can lead to confusion, we believe that it is more appropriate to define a minimum number of one iteration for the inception phase as well.

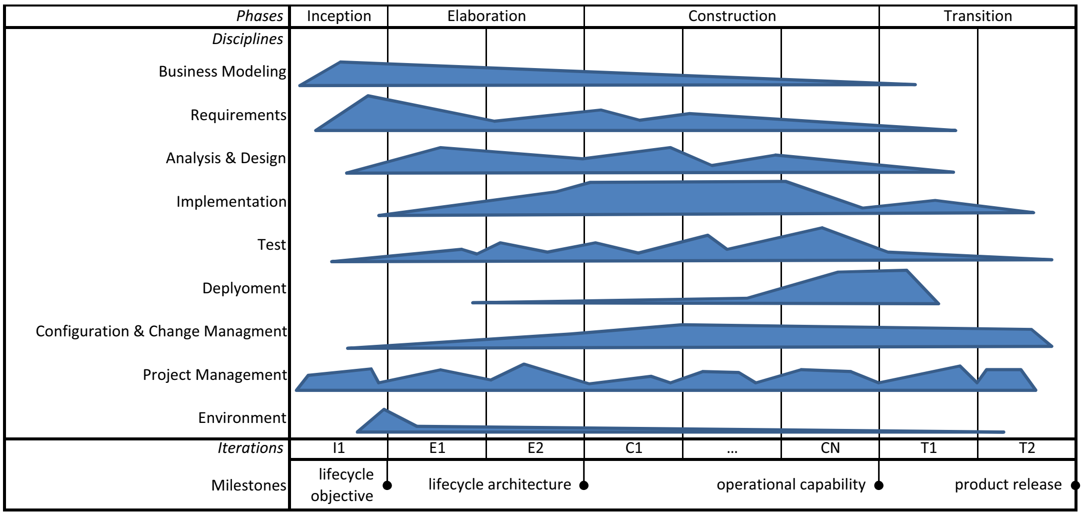

Figure 3.3: The two dimensions of the RUP: disciplines and phases as presented by Kruchten (2006).

Figure 3.3 also effectively communicates how the activities in the disciplines unfold along the timeline of the project. It illustrates the different workloads in the disciplines throughout the project and highlights the fact that the workload is dynamic and does not remain constant. This property is not directly represented in Figure 3.2 and it is therefore important to view these two Figures together. When only looking at Figure 3.2, one might get the impression that all disciplines receive the same amount of attention within an iteration. However, this is not the case. For example, in the first iterations more activities from the requirements discipline are performed, while in later iterations activities from the implementation and testing discipline form the major workload.

The Open Unified Process (OpenUP) and the Agile Unified Process (AUP)

Streamlined versions of the RUP have been proposed to better suit the needs of smaller and more flexible projects. The first one is the Open Unified Process (OpenUP), a simplified version of the original RUP (Balduino, 2007; Kroll and MacIsaac, 2006). It essentially contains the same practices and principles as the RUP, but the number of activities and workflows is reduced to better suit the needs of small project teams. The business modeling and environment disciplines are completely omitted and certain aspects of the other disciplines are omitted as well. Also, the number of roles, tasks and artifacts is cut down. The four phases remain the same, but the OpenUP additionally organizes the work according to three different levels. The most granular level is the personal level on which the work is carried out in so-called microincrements. The work items on this level typically span several hours to a few days and are the direct outcome of a team members work. On the team level the work progresses in iterations which typically span several weeks. The outcome of an iteration is a demo-able or shippable product. The highest level, the stakeholder level, spans the entire project lifecycle and divides the project into the same four phases as the RUP.

The Agile Unified Process (AUP) is also a streamlined version of the RUP with additional input from agile methodologies such as test driven development and agile change management (Ambler, 2005, 2006). The goal is to provide a process that is understood easily and that can be applied for the development of business applications. The process is serial in the large, meaning that it is conducted in a serial manner along the same four phases as in the RUP. And it is iterative in the small, meaning that the disciplines are performed in an iterative fashion. The number of disciplines is reduced to seven, whereas the business modeling, requirements and analysis & design disciplines of the RUP are covered in the modeling discipline. In difference to the RUP, the AUP distinguishes between development release iterations and production release iterations. At the end of each iteration either a development or a production release is deployed. The development release is deployed within a test area and is subject to testing and quality assurance. A production release is mature enough to be released and deployed in the target environment. Typically, a certain number of development releases are produced before the first production release is deployed. The production release can be thought of as version one of the software while the following production releases are the evolution of this software as version two, three, and so forth. Between two consecutive production releases additional development releases are produced. The number of development release iterations that precede the first production release is typically larger than the number of development release iterations between two consecutive production releases. This release model is depicted in Figure 3.4.

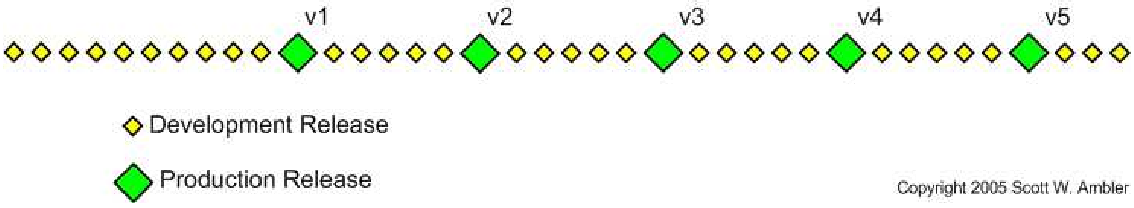

Figure 3.4: The release model of the AUP as presented by Ambler (2005).

Agile Methodologies

As an alternative to document-driven and high ceremony processes, agile methods started to emerge at the turn of the millennium. Instead of extensively documenting the system or precisely following each step of the process, agile methods advocate a lean and low ceremony process. The focus is on the creation of a high quality product that is up to the expectations of the users. This spirit is captured in the agile manifesto which was postulated in 2001 by several leaders and professionals in the software engineering field (Fowler and Highsmith, 2001). The agile manifesto includes the following four principles:

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

Several methodologies evolved that generally follow these principles and are called agile. It can be observed that agile methodologies are rather grounded in principles, values and best practices than in more formal process models or well-defined workflows. As a first example, Extreme Programming (XP) is presented. This methodology was proposed by Beck (2000) and is based on five values, three principles and four activities. The five values are: communication, simplicity, feedback, courage and respect. The three principles are: feedback, assuming simplicity and embracing change. And the four activities are: coding, testing, listening and designing. A central concern in XP is the well-being of the developers. The developers are seen as capable and professional persons who can make design decisions on their own and are not just blindly implementing the software specifications that were created by someone else. Another feature of XP is the strong involvement of the stakeholder. The software is produced in constant cooperation with the stakeholder and a representative of the stakeholder should always be available to clarify questions that might arise during development. Furthermore, the process is based on short development cycles and continuous integration. The software is incrementally developed, refactored and small releases are constantly produced.

Scrum is another agile process in which the software is incrementally produced (Rising and Janoff, 2000; Schwaber, 2004). The process arranges the development cycle in so called sprints. A sprint is a period of two to four weeks in which an increment is implemented. The requirements are frozen during this period. The requirements are collected in a so-called backlog which is a prioritized list of the requirements. Before a sprint starts a certain number of requirements is selected which is going to be implemented in this sprint. Meetings are a cornerstone in Scrum and the process distinguishes between different types of meetings. The daily scrum meeting is a time boxed meeting lasting between fifteen and thirty minutes. In this meeting all project members report on their work progress, explain what kind of obstacles they have encountered and describe what they plan to work on next. Identified problems are not resolved in this meeting, but additional meetings are scheduled to work on these issues. Further meetings include the sprint planning meeting, the sprint review meeting and the sprint retrospective.

The Dynamic Systems Development Method (DSDM) also advocates an iterative and incremental process with the continuous involvement of users (Coleman and Verbruggen, 1998). In contrast to Scrum and Extreme Programming, DSDM is more rigorous and defines a bigger set of procedures and deliverables. The process consists of five stages. The first two stages, the feasibility study and the business study, are conducted sequentially while the remaining three stages are conducted iteratively. In the functional model iteration the requirements are elicited and a design prototype is created. In the design and build iteration a functional prototype is created which is iteratively refined and evolves into the final product. In the implementation stage the created product is delivered to the users. The requirements are the only variable component in DSDM, while time and budget are fixed factors. The requirements are captured on a prioritized list which is based on the MoSCoW prioritization scheme. MoSCoW groups the requirements in “Must” have, “Should” have, “Could” have and “Would” have categories. If a project is running short on time or budget, the requirements with the lowest priority are dropped from the list. This approach is based on the pareto principle stating that 80% of the stakeholder’s needs come from 20% of the requirements.

Another development process which has a focus on the features that are provided by the application is Feature Driven Development (FDD) (Palmer and Felsing, 2002). It is an iterative process with short iterations that is based on five activities: develop overall model, build feature list, plan by feature, design by feature and build by feature. The features are completed along six milestones and the progress of features is captured in percentages. Whenever a milestone is reached, the feature is completed to a certain percentage. A set of tasks is associated with every milestone and as soon as all these tasks are completed, the milestone is considered complete. There are three design milestones: domain walkthrough (1% complete), design (41% complete) and design inspection (44% complete) as well as three build milestones: code (89% complete), code inspection (99% complete) and promote to build (100% complete). With this approach the current progress of the project is transparent to all project members and helps the project manager in planning the further course of the project.

Summary

Summing up the presented works in the software engineering field, we can see that a sequential process model was the starting point that later evolved into an iterative and incremental model. Especially the modern and agile software engineering processes share this characteristic. An iterative and incremental base process is found in all these processes, while the details are different from methodology to methodology. For example, Scrum enforces a quite fixed iteration length of two to four weeks, while the Agile Unified Process defines three different levels of iterations that can last days, weeks and months respectively. The user and the requirements of the application are another central aspect that is found in all the methodologies. In the Rational Unified Process the development is use case driven, Extreme Programming advocates the constant involvement of the stakeholder and, in the Dynamic Systems Development Method, the users needs are identified in the initial business study. In Scrum the requirements are captured in the backlog, in the Dynamic Systems Development Method a prioritized requirements list is used and in Feature Driven Development the progress of the project is directly measured through the completeness of the features.

These basic ideas and concepts of the more recent agile methodologies are also found in the Rational Unified Process. Kruchten (2007) has argued that agile methodologies often just give a new name to a concept that has been around for a long time and which can also be found in the Rational Unified Process. This insight essentially motivated our decision to utilize the general process model of the Rational Unified Process in our work.

Methodologies in 3D Environments

There have been efforts in research to create development methodologies for 3D environments as well. An excellent overview of these methodologies can be found in (Molina et al., 2005). In the same paper, Molina et al. propose the TRES-D (ThREe dimensional uSer interface Development) methodology, a methodology for the development of Virtual Reality applications. The TRES-D methodology consists of six major stages that describe the main development activities ranging from initial requirements specification to deployment and maintenance. The main activities of each stage are summarized in general but no details on low level processes are given. The methodology was applied during the development of a web-based 3D online store (Robles et al., 2005). Wilson et al. (2002) expressed the need for a structured development of Virtual Environments and created a methodology that not only covers the whole life cycle of the development but also provides techniques and tools to implement the different stages. The methodology is called VEDS (Virtual Environment Development Structure) and was developed over several years with the constant collaboration of potential users. While the stages and activities are similar to other proposed methodologies, the first stage includes elements that are not considered in other works. This stage is dedicated to the preparation and includes activities to evaluate the suitability of Virtual Environments for the application to be developed. It is encouraged to also look at other technologies and to possibly identify a technology that is better suited to implement the respective application. Another methodology that covers the whole development life cycle is named SENDA and was developed by Sánchez-Segura et al. (2003). The SENDA methodology is based on software engineering processes that were defined by the IEEE Computer Society (1991) and furthermore integrates techniques from other fields such as Human Computer Interaction and Artificial Intelligence. The design is split into three processes where the graphical aspects are designed in the 3D design process, the possible actions are specified in the actions process and the software design is specified in the system design process.

User-centered methodologies with a stronger focus on the usability aspects and the evaluation of Virtual Environments were proposed by Gabbard et al. (1999); Hix and Gabbard (2002) and Tromp et al. (2003). The process presented by Gabbard et al. (1999) consists of four stages with the first one being dedicated to user task analysis while the other stages are dedicated to evaluation. Three types of evaluations are distinguished. In expert guidelines-based evaluations, the user interface is evaluated by experts according to predefined guidelines. In formative user-centered evaluations, target users are incorporated in the evaluations, usability issues are identified and a refined interface is created. In the last stage, the user interface is compared with other types of interfaces and the performance of the same tasks across all these interfaces is evaluated. The result of this process is a usable and useful user interface prototype. It might be criticized that the comparison with other types of interfaces is conducted in the last stage. If problems are encountered at this stage of the development, it will be harder or even impossible to correct these problems. As the evaluations in our process model are based on these types of evaluations as well, we suggest to perform summative evaluations earlier in the project if this is possible. Tromp et al. (2003) present the user-centered development of a Collaborative Virtual Environment. The environment was built in three iterations starting with feasibility studies and an user needs analysis. Evaluations take a central role to improve the user interface and were carried out in four threads of work: usability inspection, observational evaluations, consumer evaluations and the formulation of guidelines. They already employed evaluations in the first stages of the development where a consumer evaluation was performed to identify the users needs and requirements.

Another framework for the design and evaluation of Collaborative Virtual Environments was proposed by Dang et al. (2008). In an iterative process, the environment is first designed, then developed and then evaluated. Evaluations can take the form of expert inspection-based evaluations and observational evaluations with users. A Collaborative Virtual Environment was created to verify the suitability of this process and was evaluated in an informal user study. The work of Menchaca et al. (2005) also deals with Collaborative Virtual Environments and they present specific tools for the realization of web-based 3D Collaborative Virtual Environments. Based on the notion of social groups a conceptual model of the environment is created and interactions among participants are modeled via graphs. A programming framework was created to facilitate the implementation which includes methods for automatically generating classes out of the interaction graphs. These tools are integrated in the first three stages of a development cycle (Analysis, Design, Implementation) in an effort to define a methodology. Fencott (2004) focuses on the aesthetic characteristics of Virtual Environments and developed a design methodology. The key stages are conceptual, perceptual and structural modeling. In the conceptual modeling stage background research activities take place and initial designs of the world are created. The perceptual modeling stage is influenced by perception theory and the experiences and perceptual opportunities are modeled via perceptual maps. Structural modeling is executed alongside the other two stages and refers to the creation of software specifications for the realization of the 3D environment.

The same team of researchers that developed the TRES-D methodology also proposed the IDEAS methodology for the development of 2D and 3D user interfaces (Molina et al., 2003). This methodology follows a model-based approach where 2D as well as 3D user interfaces are automatically generated. The properties of the interface are first established in requirements, analysis and design phases after which abstract representations of the user interfaces are created. These abstract representations are then used to create concrete user interfaces in the last step. This approach is related to the work of González-Calleros et al. (2009) who describe a method to automatically generate 3D user interfaces in three steps. Based on the identified tasks and concepts, abstract user interface containers are defined in the first step. In the next step, concrete user interfaces are created out of these abstract containers. The concrete user interfaces are platform independent. Finally, operational user interfaces for specific target platforms are created in the last step which enable users to interact with the system.

Summary

Similar to the presented software engineering methodologies, the 3D environment methodologies also share certain characteristics that are mostly found in the software engineering methodologies as well. Most of them build on an iterative process and applications are developed incrementally. Furthermore, they have a strong focus on the user and the tasks the user is going to perform. In contrast to the software engineering methodologies, the 3D environment methodologies put a stronger focus on the evaluation of the application from a user's point of view. The software engineering methodologies often include detailed procedures on how the source code is to be tested, but they remain vague on user evaluations of the application. The 3D environment methodologies provide more guidance in this regard and evaluation procedures and methods are covered in greater detail.

3.2 The Process Model for 3D Virtual World Application Development

The general process model of the RUP provides a good basis to derive a more specific process model that is tailored at application development in 3D Virtual Worlds. The RUP has a long history, is well established, clearly defined and many of the RUP's principles are also found in the more recent agile methodologies (Kruchten, 2007). Additionally, the RUP was also used in the past to define new process models like The Open Unified Process (Balduino, 2007) and the Agile Unified Process (Ambler, 2006). In contrast to the RUP where the central focus is the development of source code, the process model we are proposing is defined on a more general level with a stronger focus on evaluation. The implementation is a specific step in this model, but the details on how the implementation is performed are out of the scope of the model. The process is furthermore tailored at small projects that encompass between one and nine people and it is intended for the development of user-centric applications that involve interactions with end users inside a 3D Virtual World.

The General Structure

Use-case driven. Like in the RUP, the process model is use-case driven and the goal is to create an application that fulfills the needs of the user. While the user also plays a central role in other methodologies, in the context of 3D Virtual Worlds the user focus is of even greater importance, as this technology is not yet fully established and understood.

Architecture centric. The architecture centric nature of the RUP is applied in the sense that a certain 3D technology must be chosen upon which the application is developed. The 3D technology is the base architecture upon which the application is created. The process model assumes that a sufficiently mature 3D technology is chosen. The development of a new game engine or a new 3D environment is not supported by the process model.

Iterative and Incremental. In Section 3.1 we saw that most methodologies, in the software engineering as well as in the 3D Virtual World domain, build upon the concept of iterative and incremental development. The iterative cycle is also a key concept in the RUP and applications are created in the same manner in our proposed process model.

The iterative cycle of the process model is shown in Figure 3.5. We identified eight disciplines which capture the necessary activities for 3D Virtual World application development and which are carried out iteratively: introduction, requirements, abstract design, technology selection, realization, evaluation and deployment. These disciplines correspond to the six engineering disciplines of the RUP. Due to the orientation of the process towards small projects, the project management activities can be captured within one discipline. The three supporting disciplines of the RUP (project management, environment and configuration & change management) are subsumed in the project management discipline. The introduction discipline is devoted to the familiarization with 3D Virtual Worlds and to develop an understanding of the nature of these environments. This discipline is intended for those members of the project team who have not worked with 3D Virtual Worlds before. The activities of this discipline are carried out at the beginning of the project only. The requirements discipline has the goal of establishing the requirements

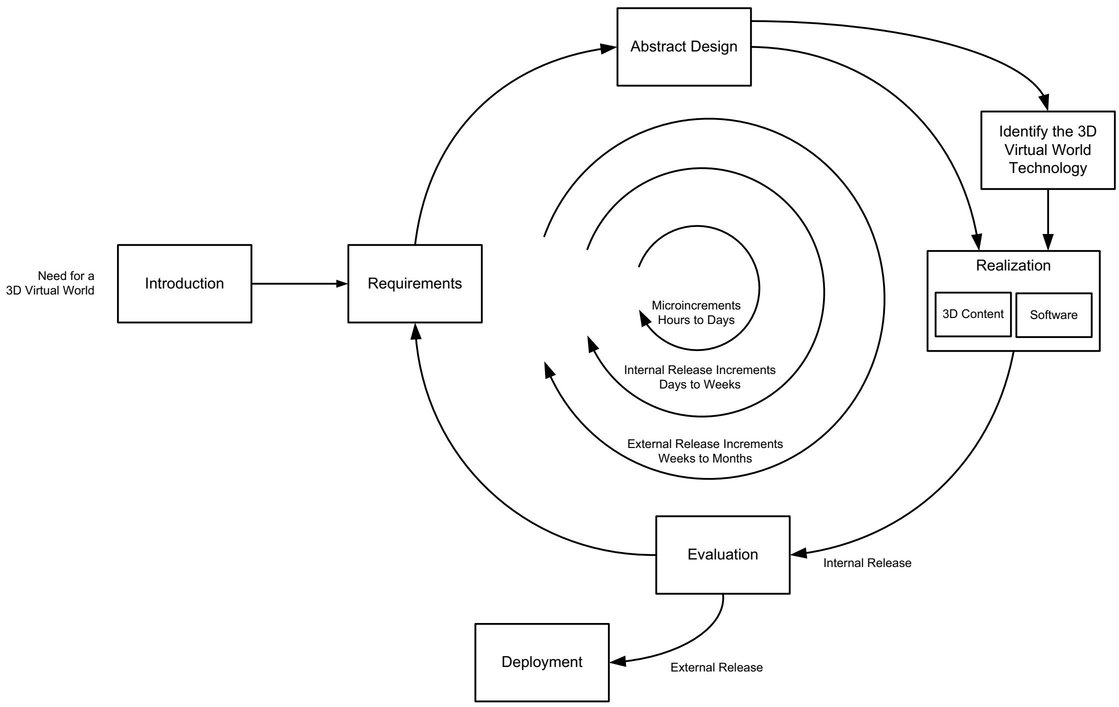

Figure 3.5: The iterative/incremental cycle of the process model.

and for determining the needs of the users. In the abstract design discipline, technology independent designs of the 3D Virtual World are created. The subsequent step in the iterative cycle either leads to the technology selection discipline or the realization discipline. In the technology selection discipline a suitable 3D Virtual World is chosen based on the identified requirements and the created abstract designs. Typically, the activities in the technology selection discipline are only carried out in the first few iterations or they might be skipped completely, if the 3D Virtual World was already determined before the project started. The realization discipline deals with the transformation of the abstract design into an executable application. The evaluation discipline has the primarily goal to evaluate the application in terms of usability and to verify that the functionality was realized according to the needs of the users. As soon as a certain quality standard can be ascertained through the evaluations, the application is ready for deployment. The tasks of this activity are covered in the deployment discipline.

Similar to the Open Unified Process, we distinguish between three different types of iterations: microincrements, internal release iterations and external release iterations. The specific functionalities of the application are implemented in microincrements that can range from several hours to a couple of days. The output of these microincrements is then aggregated in internal releases which are created in internal release iterations that typically span one to several weeks. The application is released externally and deployed in the target environment in external release iterations. An external release is typically performed every few weeks or months.

It is important to understand that not necessarily activities from all disciplines are carried out within one iteration. For example, in the beginning of the project a typical iteration will encompass activities from the requirements, abstract design and evaluation disciplines. In short iterations, the requirements are identified, first sketches are created as abstract designs and these requirements and design sketches are evaluated in an ad-hoc fashion by the project team with the possible involvement of target users. There is no need to conduct activities from the technology selection and realization disciplines at this stage. This characteristic is captured in Figure 3.6 which illustrates how the activities in the disciplines unfold along the timeline of the project. Note that this is only one possible (but quite general) arrangement of the workload and the iterations. The actual number of iterations and the workload throughout the project is different from project to project. Like in the RUP, the development timeline is divided into phases, whereas in our process model the transition phase is omitted. A separate transition phase is not necessary in our model, as the process is aimed at small projects where an elaborate transition phase is not required. The transition of the application into the target environment is modeled via the external release iterations instead.

In the inception phase, the project team develops an understanding of the properties of 3D Virtual Worlds and establishes a vision for the application that is going to be created. The elaboration phase has the goal to work out an initial set of requirements and to determine a 3D Virtual World technology that will be used for the realization. Once the 3D Virtual World was selected and an architecture for the further development exists, the application is created in the construction phase. In a regular interval internal releases are created until the application is mature enough to be released externally.

The Roles

The process model encompasses the following set of roles which can be played by the project members. A project member is not attached to a certain role, but is able to play different roles throughout the project. For example, a project member may play the analyst role in the morning and work on the requirements, in the afternoon she might switch into the software engineer role and implement some functionality and in the evening she might perform project management activities in the project manger role. The roles are as follows:

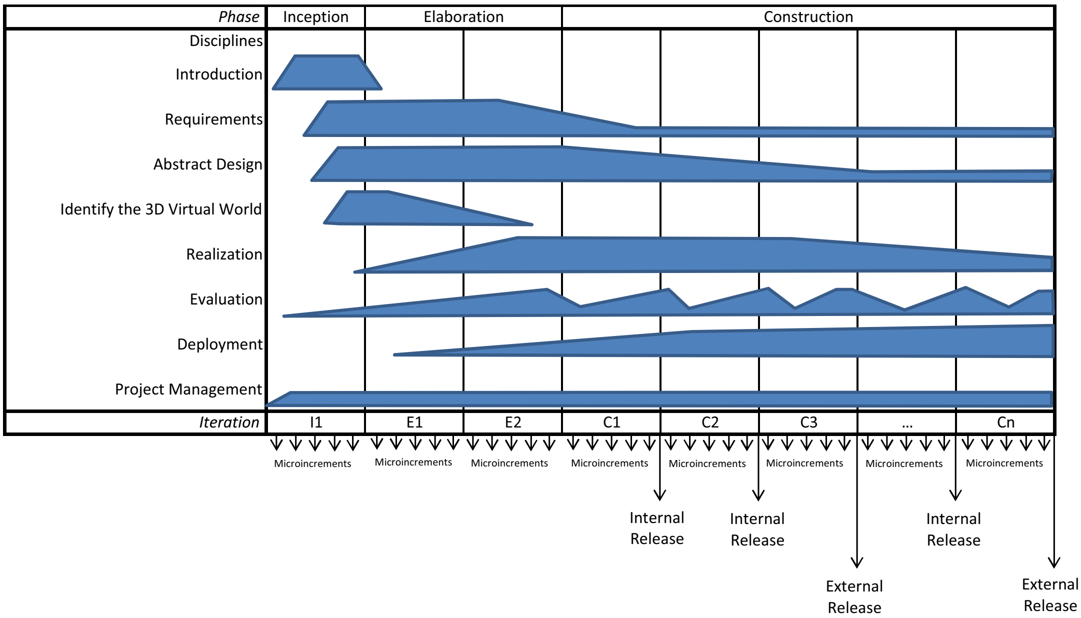

Figure 3.6: The phases of the process model.

- **Analyst:** The analyst or requirements engineer is responsible to identify the needs of the users and to capture them in the requirements. This role closely works together with the end user, stakeholder and domain expert in order to elicit the requirements and to understand what is needed by the users.

- **Domain Expert:** The domain expert has knowledge of the target domain for which the application is developed. This role especially supports the analyst and the evaluator and works together with the end user and the stakeholder.

- **End User:** The end user is a person of the target population who will actually use the application when it is finished. The end user is consulted in the beginning of the project to identify the requirements and takes part in evaluations throughout the whole project.

- **Stakeholder:** A person in this role is a representative of the stakeholder for whom the application is developed. The stakeholder does not necessarily have to be an external person. For example, if an application is developed in-house or is part of a research project, the stakeholder can be an internal person as well. The stakeholder identifies the scope of the project and works together with the project manager and the end user.

- **Project Manager:** The project manager is responsible for identifying the requirements that will be realized and for planning the iterations and timeline of the project. The project manager is the primary contact person for the stakeholder and leads the whole project team.

- **3D Content Creator:** All the content in the 3D Virtual World is created by the 3D content creator. This encompasses the landscape of the world, the objects and the avatars. If necessary there can be several 3D content creators with different specializations. For example, one might be responsible for the texture creation while the other works on the animations of the avatars. The 3D content creator works closely together with the interaction designer, the software engineer, the analyst, the evaluator and the end user.

- **Interaction Designer:** The interaction designer is responsible for modeling the interactive elements in the environment. This includes the interactions inside the 3D Virtual World on the one hand and the design of the user interface (i.e. the head-up display, dialogs, input masks, etc.) on the other hand. The interaction designer works together with the 3D content creator, the software engineer, the analyst, the evaluator and the end user.

- **Software Engineer:** The program logic of the application is realized by the software engineer. This encompasses the design, writing and testing of source code. The software engineer works together with the interaction designer, the 3D content creator, the analyst and the tester.

- **Tester:** The tester is a person that is capable to test the developed environment and to identify and report bugs. The tester typically tests the application from the view point of the end user, but the testing might also be performed on a lower level such as source code testing. The tester works together with the interaction designer, software engineer, 3D content creator and analyst.

- **Evaluator:** The evaluator is responsible to conduct evaluations with end users and to determine if the application fulfills the needs of the end users. The evaluator works together with the end user, the analyst, the tester, the software engineer, the 3D content creator and the interaction designer.

- **Any:** The any role covers those kind of tasks that can be performed by all project members and which do not fall into the domain of a specific other role.

The Disciplines

The Introduction Discipline

The introduction discipline is dedicated to the familiarization with 3D Virtual Worlds and for developing an understanding of their possibilities and limitations. This discipline is especially intended for project teams or members of a project team that have not worked with this technology before.

In order to get a feeling for the technology, the first step is to explore different 3D Virtual Worlds. A hands-on experience provides an easy access and helps to quickly learn and familiarize oneself with this technology. Sivan (2008) proposed a recipe for active research in 3D Virtual Worlds which contains the essential activities to get familiar with 3D Virtual Worlds. Before the research is started, a general vision of the project is established and the scope of the project is defined. This helps to correlate the expectations of the project members with the vision of the project and enables the identification of opportunities as well as barriers.

The next step is to participate in different 3D Virtual Worlds and to learn about their characteristics. Second Life provides a good starting point as it is one of the most mature and most active 3D Virtual Worlds. In this world it is possible to explore a wide range of different 3D spaces and applications, to engage in the building of 3D objects and to participate in an active community. Additional worlds that might be used for the exploration are those introduced in Chapter 2. This exploration phase is accompanied by a catalog of 3D Virtual World criteria that conveys the key characteristics of these environments. This catalog is based on (Baumgartner, 2008) and was updated and extended according to our experiences. The catalog comprises categories such as barriers to entry, avatar features, performance and graphics. It will also be used later in the process during the selection of the 3D Virtual World. The complete catalog can be found in Appendix A. Additionally, the knowledge of usability principles is essential for being able to assess the applicability of 3D Virtual Worlds and to be able to identify opportunities. Therefore, usability guidelines for 3D environments should be studied during the exploration phase and one should try to apply these guidelines in the environments that are explored. These guidelines can be found in the literature: Gabbard and Hix (1997) presented a usability taxonomy, Stanney et al. (2003) identified usability criteria and Bowman et al. (2004) provide guidelines on 3D user interface design. Examples of such guidelines are "the integration of travel and wayfinding components" (Bowman et al., 2004, p. 253), "to take into account the number and locations of potential users" (Gabbard and Hix, 1997, p. 19) and "to seamlessly integrate auditory display into user task activity" (Stanney et al., 2003,

p. 465).

The knowledge and experiences that are acquired in the exploration phase are collected in a knowledge base. After the exploration is finished, a workshop is held in which the experiences are discussed and the vision of the project is elaborated.

Artifacts: Vision document and knowledge base
Roles: Any

The Requirements Discipline

In the requirements discipline the goal is to develop an understanding of the users needs and to identify the tasks and purpose of the application. The interactive nature of 3D Virtual Worlds and the established practices in related methodologies indicate that the needs of the users should be the central interest. It is advisable to already integrate users from the target population in early iterations to get valuable input for the formulation of the requirements. Furthermore, the application domain is an important facet in this discipline. Domain experts are consulted in order to properly formulate the requirements with respect to the domain characteristics. In cooperation with domain experts, a user task analysis is conducted and the requirements of the application are derived. For example, Robles et al. (2005) observed the behavior of people in a shop environment and conducted interviews with employees to define the requirements of a 3D online store and Tromp et al. (2003) used consumer evaluations to identify the requirements.

After the user tasks and requirements were established, use cases and usage scenarios are created. Use cases capture the different activities that are carried out in the environment while usage scenarios describe longer interaction sequences defining the scenarios in which the application will be used. These methods have proven to be effective means in other methodologies as well (Wilson et al., 2002; Gabbard et al., 1999; Hix and Gabbard, 2002; Molina et al., 2005; Fencott, 2004).

Artifacts: Requirements document, use cases and usage scenarios
Roles: Analyst, end user, domain expert, stakeholder and project manager

The Abstract Design Discipline

The abstract design discipline deals with the creation of technology independent designs that illustrate what the 3D Virtual World will look like and which kind of functions will be accessible to the user through the user interface and the interaction with the environment.

An abstract design phase is also a constituent part in the methodology of Molina et al. (2005) and Fencott (2004) includes a similar phase which is called conceptual design.

Based on the users needs that were identified by the analyst, the 3D content creator in collaboration with the interaction designer develops the designs. The 3D content creator is responsible for drawing sketches of the 3D Virtual World in order to get an impression on the atmosphere and the structure of the world. The interaction designer is responsible for the design of the 2D user interfaces and defines the interactive elements in the sketches of the 3D content creator. These designs materialize as paper prototypes, user interface mockups, sketches and floor plans which are created in other methodologies as well (Wilson et al., 2002; Molina et al., 2005; Fencott, 2004; Dang et al., 2008; Robles et al., 2005). In the first iterations, the created design documents are an important decision support for the selection of the 3D Virtual World technology.

Artifacts: 3D designs, user interface designs, floor plans, sketches
Roles: 3D content creator, interaction designer and analyst

The 3D Virtual World Selection Discipline

The 3D Virtual World technology that is chosen has a great influence on the feasibility of the implementation. We believe that a process for choosing the appropriate technology is essential and have therefore created a method for selecting the best suited technology. The method is based on research in the domain of software evaluation where the goal is to evaluate different software products against a set of requirements and to chose the best suited software product for the given requirements. In particular, the method is based on research by Punter (1997) and Colombo and Guerra (2002) which use checklists for evaluating qualitative criteria of software products.

A checklist contains questions that are related to quality characteristics which are of importance for the application to be developed. These questions are derived from the catalog of 3D Virtual World characteristics that was introduced as part of the introduction discipline. They are formulated by the project team on basis of the categories in the catalog and with respect to the requirements of the application. Example questions are: Is avatar customization supported? How well is the privacy protected? Is it possible to fly around with the avatar? The questions are then included in the checklist and different candidate technologies are evaluated against them. An overview of the questions that were used in the Itchy Feet project for the selection of the 3D Virtual World can be found in Appendix B. An example of a checklist is shown in Table 3.1. For each candidate technology the question is evaluated on a rating scale ranging from 0 to 5. This value

Question	**VW 1**	**VW 2**	...	**VW k**
Question 1	$v_1^1 * w_1$	$v_1^2 * w_1$	...	$v_1^k * w_1$
$\vdots$	$\vdots$	$\vdots$		$\vdots$
Question n	$v_n^1 * w_n$	$v_n^2 * w_n$	...	$v_n^k * w_n$
Sum	$s_1 = \sum v_i^1 * w_i$	$s_2 = \sum v_i^2 * w_i$		$s_k = \sum v_i^k * w_i$

Table 3.1: Checklist for the evaluation of different 3D Virtual World technologies.

(v_i^j) indicates the degree to which the characteristic is fulfilled by the technology. Yes/No questions receive a value of 5 for a true proposition and 0 for a false one. If a question is not applicable in the context of a technology, a NA (not applicable) answer is given and the question receives a value of 0. Additionally, the importance of every question is defined by a weight (w_i) that ranges from 1 to 3 where a weight of 1 refers to a characteristic with low importance, 2 refers to normal importance and 3 refers to high importance.

The scores for each technology are calculated and serve as a basis for the decision on the 3D Virtual World technology. After the technology was selected, a change of previous design or requirements documents might become necessary due to characteristics and limitations of the chosen technology that were not known beforehand.

Artifacts: Selection checklist
Roles: 3D content creator, interaction designer, software engineer

The Realization Discipline

The realization discipline deals with the transformation of the requirements, designs and use cases into an executable application. In the realization discipline we distinguish between 3D content creation and software development (cf. Figure 3.5). 3D content creation refers to the modeling of the 3D Virtual World through the 3D content creator. This includes the modeling of the landscape, the objects and the textures, but also the integration of sound. Software development refers to the implementation of the program logic and the creation of the user interfaces. These two areas are perfectly suited for parallelization which is why they are depicted in parallel in Figure 3.5. The 3D content can be created while the program logic is implemented and the 3D content creators, interaction designer and software engineers only have to agree on the interaction interface that links the 3D content with the program logic. Furthermore, a lot of objects are typically non-interactive or have a trivial type of interaction (e.g. a description is printed out when the object is clicked). Examples include environment objects such as trees, bushes or rocks, but also entire buildings and interior objects in these buildings. In these cases the interaction interface will be simple and the degree of dependency between the work output of the 3D content creator and the software engineer will be low. Note that there might be applications in which the 3D content is generated automatically or acquired from a third party. In these cases the 3D content creator might perform few or no activities and the content creation is part of the software development activities.

In terms of defining the interaction interface, the interaction designer, 3D content creator and software engineer work together closely. The interaction designer specifies the types of interaction in the 3D Virtual World and designs the user interfaces. The interaction designer is the link between the 3D content creator and the software engineer and is responsible to communicate the interaction interfaces and to establish the co-operation between these roles. The details of the 3D content creation as well as the implementation depend on the technology that was chosen in the selection discipline and on the established practices in the work environment.

Artifacts: Interaction model and implementation model
Roles: 3D content creator, software engineer, interaction designer and tester

The Evaluation Discipline

Evaluations in the first iterations take the form of expert-guideline based evaluations and formative evaluations (Gabbard et al., 1999). In an expert-guideline based evaluation the interfaces and designs are evaluated by experts according to usability and design guidelines. Identified problems and issues are reported and updated versions of the designs are created. In our process model these experts adopt the tester role, evaluate the design and report identified issues. These issues are then resolved by the interaction designer and 3D content creator in the next iteration. In a formative evaluation the application is evaluated with target users that execute tasks and whose behavior is observed. In order to involve users in early iterations, paper-based prototypes and interface mockups are used to create a first usage experience of the application. In case that end users are not available on a regular basis, these formative evaluations might also be performed by project members that are less involved in the interface design or other persons that are available in the work environment.

In later iterations, when functional prototypes become available and the first internal releases are created, formative and summative evaluations (Gabbard et al., 1999) are conducted. In contrast to the early iterations, the formative evaluations are executed on functional prototypes at this time. The degree of detail of these evaluations ranges from ad-hoc evaluations in the beginning to more systematically executed evaluations in later stages. We found that qualitative evaluations proved to be especially useful at this point. In a qualitative evaluation the focus is on the opinion of the user and it is easier to discover the attitudes towards the application than in quantitative experiments. A summative evaluation has the goal of comparing the task performance in the developed application with the performance of the same tasks in other systems. While Gabbard et al. (1999) place the summative evaluation at the end of the development cycle, we suggest to perform these evaluations at an earlier stage already. It is then easier to correct identified problems and they do not remain undiscovered until the application is finished. Note that the conduction of summative evaluations is not necessary in every project. Typically, a summative evaluation is carried out in research focused applications which explore a new technique or feature whose effectiveness is compared with other systems.

Artifacts: Evaluation report
Roles: Evaluator, end user, tester and any role

The Deployment Discipline

The last discipline deals with the deployment of the application. In Section 3.2 the concept of microincrements, internal and external releases was introduced. The internal releases are deployed internally and might be subject to user evaluations. External releases are deployed in the target environment enabling end users to use the application. In terms of the external releases we distinguish between two different types of applications: applications that are packaged as a software product and installed in the target environment and applications that are deployed online. In the case that the application is directly deployed to a server, the software developer can directly perform the deployment from within the development environment. In the case that the release has to be deployed in a target organization, the software developer will create an installation package and the deployment can also be performed by a person in the any role.

The deployment strategy and the number of iterations until the first external release becomes available can vary greatly depending on the type of application that is developed. We distinguish between two different deployment strategies: feature complete deployment and rapid deployment. Under the term feature complete deployment we understand an application that is developed in several iterations until all features are integrated and which is then externally released. In contrast, with rapid deployment a functional application is delivered quickly, possibly after the first construction iteration already. At this point only a small subset of features is available, but users are able to use the application much earlier than with the feature complete deployment strategy. The rapid deployment strategy works well with applications that are deployed online. New features are then constantly added to the application and the number of available functions steadily grows. This approach is based on development practices of Web 2.0 applications where a first version is released early and new features are slipstreamed into the online application (O'Reilly, 2005). The application is steadily improved based on the feedback of users and information on the usage frequency of features. We believe that this deployment strategy is especially well suited for applications in online 3D Virtual Worlds. In this case no re-distribution of the application is required and users instantly profit from the added value of new features. In contrast, if the application is designed to be installed and executed on target machines, the feature complete strategy is better suited. In this case the deployment is more expensive and cannot be performed every time when a new feature is added.

Artifacts: Deployment plan
Roles: Software engineer and any role

The Project Management Discipline

The project management disciplines deals with the management of the project including the configuration and change management, the planning of the iterations and the management of the environment. The environment management deals with the provision of the necessary infrastructure and tools that are required for the development of the application. The configuration and change management defines how the artifacts are managed over time and what kind of system is employed to store and track the different versions of the artifacts. At any time it must be possible to retrieve the prior versions and history of an artifact in order to be able to revert to a previous project state if necessary. This is especially important in the light of an iterative process where artifacts are constantly updated and revised.

The iteration planning defines the tasks that are going to be accomplished within the next iterations. The scope of the iteration and the requirements that will be realized within the iteration are determined. In terms of planning granularity, we follow the suggestions of Appelo (2008). He argues that the level of detail should decrease the farther away the iteration is. The tasks of the subsequent iterations are better known than the tasks of iterations that lie farther in the future. Therefore, it will be easier to exactly specify the tasks for the next iterations, while the tasks of more distant iterations are defined more vaguely and might also be subject to change in the future.

The project management discipline furthermore encompasses the negotiation with the stakeholder and the reaching of a mutual agreement on the functionality that will be realized.

Artifacts: Project plan and iteration plan
Roles: Project manager, analyst, domain expert and stakeholder

3.3 Lessons learned from the Itchy Feet Project

In the Itchy Feet project we developed one 3D Virtual World which included two different applications: the 3D e-Tourism environment Itchy Feet and the cultural learning application ICURA. At the beginning of the project we used an initial version of the presented process model to develop the 3D e-Tourism environment. At the time when we developed ICURA, we already had a better understanding of the development process which stronger resembled the present version of the process model. In the following we outline the development process, show how it fits into the process model and discuss the lessons we learned.

The 3D e-Tourism Environment Itchy Feet

Our interest in 3D Virtual Worlds was motivated by the unique characteristics of these environments and the advantages 3D environments can offer in the tourism domain. Research reports were our initial source of information and we additionally started to participate in 3D Virtual Worlds to get a feeling for this technology. The 3D Virtual World of Second Life proved to be a well-suited environment for the familiarization stage and later we also conducted research in this world (Froschauer et al., 2009). Furthermore, we experimented with different 3D technologies for a potential usage in the Itchy Feet project. We developed the selection procedure that was presented in Section 3.2 and used it for the evaluation of four different technologies: the Active Worlds platform, the Torque game engine, the Q engine and Java 3D. In contrast to the current process model, the questions were not organized on basis of the 3D Virtual World criteria catalog, but were organized more generally according to the categories of the ISO 9126 standard on software product quality (International Organization for Standardization (ISO), 2003). These categories included learnability, understandability, portability, installability and attractiveness. The full list of categories including the questions that we had formulated can be found in Appendix B. The technologies were then evaluated and rated according to these questions and based on this knowledge, the Torque game engine was identified to be the most suitable technology. Therefore, we utilized it for the creation of the 3D Virtual World.

In contrast to the present version of the process model, we had conducted the selection of the technology in the beginning of the project already. At that time we did have several ideas for an application in a 3D Virtual World, but no detailed analysis had been made yet. In later stages when the requirements were better understood and also new requirements emerged, we found that the Torque game engine lacked support for the implementation of some of these requirements. We came to the insight that we should have considered the application specific requirements in the technology selection as well. Therefore, the technology selection was moved after the requirements and abstract design disciplines in the current process model, in order to establish a detailed understanding of the features before the selection process takes place.

We then carried out a task analysis where we identified the essential functions for an application in the e-Tourism domain. This was done through the analysis of e-Tourism portals where we compared the different characteristics of such platforms and identified the key features (Dippelreiter et al., 2008). Furthermore, we identified different types of roles that were expected to use the application. This, for example, included a consumer role representing the users and an employee role representing travel agents at a travel agency. For the identified tasks and roles we then modeled use cases to specify the task sequences in more detail. As a next step we started with the initial design and created user-interface mockups, drew floor plans and made sketches of the 3D Virtual World. The interface mockups and the floor plans were realized with a diagramming software while the sketches were drawn by hand. During this stage we also had created a detailed software requirements specification in which the different components and the message exchanges between them were defined. This specification exhibited a high level of detail and was intended to be used as a blueprint for the implementation. However, later in the development it turned out that this specification had been too detailed. A great effort was required to update the specification according to changes in the requirements and we came to the insight that a smaller level of detail is favorable in order to be able to react quicker to any changes in the specification. The specification and the implementation started to drift apart and in the end we stopped to update the specification and focused on the other design documents instead. The interface mockups, the use cases, the sketches and the floor plans have proven to be better suited in this regard.

During the realization we observed that the implementation of the software and the creation of the 3D content can be performed independently from each other and that these tasks are ideally suited for parallelization. At the same time as the source code was written, the 3D world and the 3D objects were created. It was only necessary that the interaction interface was defined clearly and that the work progress of the designers was transparent to the developers and vice versa. This helped us to quickly identify problems and mismatches between the source code and the 3D content which could then be resolved with greater ease as when we would have discovered them later.

We followed usability heuristics and guidelines during the implementation in order to create a usable application and conducted several expert evaluations in which the interface was assessed according to these documents. The identified problems were addressed in the following and the application evolved into a feature complete version in an iterative fashion. This version was then the subject of a formative user evaluation with 20 test users. The evaluation provided us with valuable insights on the usability and the users attitudes towards 3D e-Tourism environments. The large number of users was specific to our project setting as we were interested in evaluating the acceptance of 3D Virtual Worlds in tourism. In general, a fewer number of users (around five) should be sufficient to detect most of the usability problems. The formative evaluation as part of this thesis is presented in detail in Chapter 5.

The Cultural Learning Application ICURA

Later in the project we created a second 3D Virtual World application that extended the 3D e-Tourism environment and provided users with the possibility to learn about Japanese culture. The application is named ICURA and was realized as a serious game where users learn about Japanese culture in a playful way (Froschauer et al., 2010). The experiences that were gained during the development of the 3D e-Tourism environment enabled us to perform the development of ICURA more efficiently. We rather laid emphasis on documentation through design and use cases than creating rigorous specifications and we stronger employed the iterative process with shorter cycles and more evaluations.

In the development of ICURA it was not necessary to perform familiarization activities and there was no need to perform the 3D Virtual World selection. We had already developed an understanding of 3D Virtual Worlds during the first part of the project and the 3D Virtual World environment had been established as well. In order to address the requirement of effectively communicating knowledge to users, we identified the genre of adventure games as the most suitable type of game. In an adventure game, the user typically slips into the role of a certain character and has to solve puzzles and riddles through the interaction with other game characters. The adoption of an adventure based game enabled us to engage users by embedding the learning content in puzzles and riddles along a meaningful scenario and further allowed us to communicate knowledge in a natural way via the interaction with other characters in the environment. In the next step, we started to work on the requirements and conducted a survey to identify learning contents that are suited for the integration into the game.

A game story was created and documented as an informal textual description that captured the use cases, the interaction modalities and the learning contents. This document was iteratively refined in expert discussions. We then started to identify the elements and characters that would be required in the 3D Virtual World and created sketches of the buildings and the landscape of the 3D Virtual World. Representative photographs of Japanese architecture were selected according to which the models were designed and modeled. Again we observed that the implementation of the source code and the creation of the 3D content could perfectly be performed in parallel.

The designs were iteratively improved. We employed expert guideline based evaluations in the beginning and later performed several small informal formative evaluations with one test person. These formative evaluations provided us with great insights on usability problems and flaws in the game scenario which could then be resolved in the following. The final application was then used in a formal formative evaluation with 20 test users to get insights on the usability of the created serious game and to assess whether it is possible to communicate knowledge by playing the game. The results of the evaluation and the ICURA application are presented in detail in (Froschauer et al., 2010).

3.4 Summary

In this Chapter we proposed a holistic process model for the engineering of 3D Virtual World applications. The process model combines our experiences of developing 3D Virtual World applications and the knowledge of related works from the software engineering, 3D Virtual World and Virtual Reality domains. We first introduced and aggregated the results of these related works and then derived the principal structure of the process model which is primarily based on the Rational Unified Process. The key components are an architecture centric view, an iterative and incremental development approach and a focus on the user and the tasks the user is going to perform. Eight different disciplines were identified which capture all the necessary activities for developing 3D Virtual World applications. Finally, we discussed how the process model evolved out of the Itchy Feet project and what lessons we had learned during the implementation of the 3D e-Tourism environment Itchy Feet and the cultural learning application ICURA.

CHAPTER 4

The Itchy Feet System

The Itchy Feet system is the realization of a 3D e-Tourism environment that enabled us to learn about the development of applications in 3D Virtual Worlds and provided the testbed for conducting research in 3D Virtual Worlds and e-Tourism. The Itchy Feet system not only is a 3D Virtual World in the tourism domain, but on a more general level provides a framework for 3D e-Commerce environments. The conceptual model of this framework is based on the connection of a 3D Virtual World with a Multi-Agent System. The Multi-Agent System provides the regulatory environment for the creation of a secure and reliable e-Commerce system. And the 3D Virtual World is the access point for customers and providers to participate in the environment.

This generic framework was applied to the tourism domain and resulted in the creation of the 3D e-Tourism environment Itchy Feet. A quick overview of Itchy Feet from the perspective of the 3D Virtual World is provided in Section 4.1. This overview contains all the necessary information to understand how the system is used by the end user. The background and related work including e-Tourism, Multi-Agent Systems and their combination with 3D Virtual Worlds is then presented in Section 4.2. The generic e-Commerce framework is introduced in Section 4.3, where the focus is placed on the system architecture that facilities the connection between the Multi-Agent System and the 3D Virtual World. Section 4.4 then provides a more detailed look at the features of Itchy Feet. The business processes and the trading facilities are introduced and the message exchange between the different layers is described.

4.1 A Quick Look at Itchy Feet

The technological foundation of Itchy Feet is the connection of a Multi-Agent System to a 3D Virtual World. The Multi-Agent System is used to define the business processes and rules which are enforced in the 3D Virtual World. Every user in the 3D Virtual World is the principal of an agent in the Multi-Agent System that validates the actions of the user. Agents are visualized in the 3D Virtual World as avatars. The system is based on a three layered architecture where the 3D Virtual World is placed at the top layer, the Multi-Agent System is at the bottom layer and both components are connected through the middleware layer. Whenever a user performs an action in the 3D Virtual World, an action request is sent to the user's agent which verifies the action request in the current state of the Multi-Agent System. For example, if a user wants to enter a building, she has to press a key in front of the entrance door. A request to open the door is then sent to her agent and validated in the Multi-Agent System. If the agent is allowed to enter the respective entity in the Multi-Agent System, a response is sent back to the 3D Virtual World and the door is opened. Otherwise, the door remains closed and an information message is shown to the user.

The services of Itchy Feet are provided in three different buildings. In the Forum, the user is able to open a forum, to browse the threads, to read the entries and to participate in discussions. Professional travel agents are working in the Travel Agency and help the user with personal requests. These travel agents are represented as avatars in the 3D Virtual World and allow the user to easily get in touch with the product provider. The Travel Agency additionally contains a hotel search functionality. The user can search for a hotel room which can then directly be reserved and paid in the Travel Agency. The third building is the Auction House in which hotel rooms are auctioned. The first room provides a message board that lists upcoming auctions. A corridor leads the user to two auction rooms in which auctions are conducted. Auctioned products are paid and checked out in the payment room. The 3D Virtual World with these three buildings is shown in Figure 4.1. The Forum is at the top, the Auction House can be seen on the right and the Travel Agency is located on the left. At the bottom there is a replication of a tourist attraction, namely the St. Charles's Church in Vienna. The ICURA application can be accessed through a temple that is located outside of the visible area. The user can enter this temple, play the serious game and can then continue to explore Itchy Feet.

The Itchy Feet user interface is constructed similarly to other 3D Virtual Worlds where the different functions are accessible via buttons on the user interface. This is illustrated in Figure 4.2 which shows the 3D Virtual World from the perspective of the user. There are two buttons on the right side of the interface, one with a backpack sym-

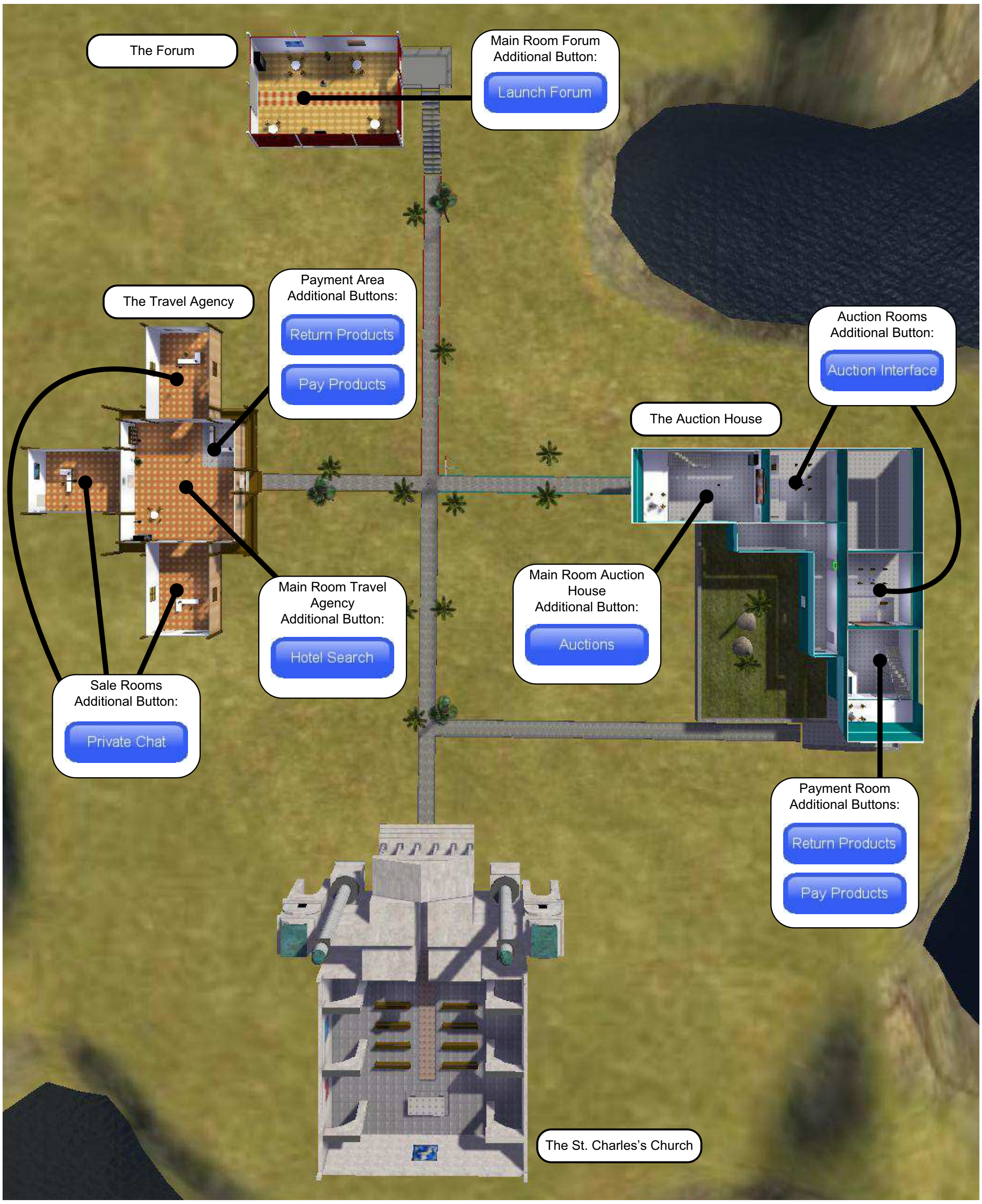

Figure 4.1: Bird's eye view of the Itchy Feet 3D Virtual World.

bol and one with a shopping cart symbol. They are used to open the inventory and the shopping cart of the user. The profile can be displayed via the "Show Profile" button in the lower right corner and the communication with other users is facilitated through the chat boxes and buttons at the bottom of the interface. The button on the left side is used to open a notepad in which the user can write down notes. In contrast to other 3D Virtual

Figure 4.2: The user interface of Itchy Feet.

Worlds, the Itchy Feet user interface is distinguished by “static” and “dynamic” buttons. Static buttons are shown at all times and the corresponding functions are accessible anywhere in the 3D Virtual World. All the buttons shown in Figure 4.2 are static buttons. In contrast, dynamic buttons are hidden or shown depending on the user context. Whenever the user enters a building or a room, the current context is evaluated and buttons appear while existing buttons may disappear on the user interface. For example, when the user enters the Travel Agency, the “Hotel Search” button is shown. If the user moves on and enters the payment area, the “Hotel Search” button is hidden and the “Return Products” and “Pay Products” buttons are shown. This approach of separating accessible functions by the physical area mimics metaphors that people are used to from the real world. Think of a shopping mall, for example. There are different stores that offer different services to a customer. At the barber you can get a haircut, in the clothing store you can shop for clothes and in the food court you can have lunch. Similarly, in Itchy Feet, the forum can be browsed in the Forum building, auctions are taking place in the Auction House and travel agents are consulted in the Travel Agency. The functional separation according to the user's location helps to keep the user interface clean. The user is not distracted or lost in a cluttered interface where all functions are accessible at once. In Figure 4.1 it is illustrated which kind of functions are available in which rooms. When the user enters a room the buttons shown in Figure 4.1 are displayed above the profile button and the respective functionality can be accessed by clicking on the button.

4.2 Background

e-Tourism

e-Tourism has created new distribution channels for tourism resulting in the establishment of numerous online booking platforms. Their services are increasingly used by customers to purchase tourism products online. A survey comparing online booking with booking at traditional travel agents gives insights on the booking behavior of customers (Bogdanovych et al., 2006). This survey showed that people are using online booking services primarily to book domestic trips, whereas international trips are more often booked with a travel agent. The main advantages of travel agents are their expertise and the face-to-face interaction when making difficult decisions. In contrast, online booking systems are more convenient, have lower response times and provide answers to inquiries in an environment familiar to most users. Note that these results were obtained in Australia and the booking behavior in other countries might be different, due to both sociological as well as geographical reasons. Berger et al. (2004) observed that Web sites in e-Tourism are rather dominated by conservative user interfaces. Especially on booking platforms users navigate through a plethora of drop down lists and selection boxes to search for tourism products. To overcome these disadvantages, new interface metaphors need to be developed. The authors employ a natural language interface enabling users to formulate a query in natural language. The advantages of this approach are the same as with online discussion forums, i.e. users can express more complex queries when using their natural language and will get more appropriate results to their search requests. Furthermore, they do not have to learn a special query language and are not required to structure their request in a way the computer understands. A field trial showed that most of the participants considered the natural language interface to be more comfortable than standard interfaces and explicitly stated their preference for this kind of interface. Itchy Feet provides a 3D Virtual World as a possible alternative to existing conservative interface approaches and combines the convenience of online booking systems with a familiar environment which people are used to from the real world. The integration of travel agents in the 3D Virtual World enables users to get directly in touch with professionals from the travel industry and resembles a face-to-face communication. Additionally, users can formulate their requests in natural language and are given direct access to a personal contact person to whom they can relate to.

The community as a constituent part of 3D Virtual Worlds also plays an important role in e-Tourism. Aschoff and Schwabe (2009) studied the growth rates of 74 online tourism communities. The communities were divided into three groups based on the size of the community. The first group included one community with more than one million members, the second group contained three communities with hundred thousand to three hundred thousand members and the third group included seventy communities with less than fifty thousands members. They call this distribution an archetypical long tail with a small head of few large communities and a long tail of many small communities. They measured the size of the community at two measure points within half a year. They found out that the communities exhibited an average relatively monthly growth of 17.7% and that the communities in the long tail are not dead, but are growing as well. This suggests that communities provide a valuable opportunity for tourism and that not only large communities are in existence, but that small sized communities also have the potential to attract users. Wang et al. (2002) established theoretical foundations for virtual tourism communities and highlighted the implications for tourism marketing. They present communities as an effective means for tourism corporations to present and communicate their products and to establish relationships to their customers. Furthermore, they argue that tourism communities can evolve to a reliable and timeliness information source that is likely to exceed the amount of information that is available through other channels. To get insights on the quality of information posted on forums, travel blogs, etc., Schwabe and Prestipino (2005) compared the information quality of online tourism communities with traditional guidebooks. They found out that online communities provide more timely information, requests can be answered more completely, and personal requests can be accomplished better. The structure of the information is the only area where guide books are more sophisticated. In order to learn about the characteristics of tourism communities, we conducted a study that compared different tourism online communities and investigated the use of Web 2.0 technologies (Dippelreiter et al., 2008). We found out that online communities in e-Tourism mostly address the pre-trip and post-trip phase of the tourism life cycle, while support during the on-trip phase is mostly neglected. Communities are used to collect and aggregate information prior to the trip and to share experiences and pictures afterwards. Interestingly, Web 2.0 technologies such as interactive maps have only been introduced sparingly and many communities use conventional technologies. Discussion forums are also still the predominant way to elaborate on tourism topics and have not been replaced by other forms of collaborations. These insights motivated the inclusion of a discussion forum in Itchy Feet to provide a place for sharing knowledge among users. Additional community features that are supported in Itchy Feet are chat functionalities and user profiles. The chat functionalities are employed to stimulate the communication and interaction between users and user profiles are included to enable the self-expression of users and to allow them to present their personal interests to other community members.

Trust in e-Commerce systems is a domain of active research and different studies show that the social presence of a web site influences trust, enjoyment, perceived usefulness and loyalty. Social presence is the sense of awareness of other people in a communication medium. Hassanein and Head (2007) conducted a study where they investigated the influence of certain interface elements on perceived social presence. Three different online stores with low, medium and high levels of social presence were created. Test subjects had to complete a certain task - buying a piece of clothing - and reported their experiences in a questionnaire. The evaluation showed that the social presence of a web site can be influenced by certain user interface elements which in turn influences the trust, enjoyment and perceived usefulness of a web site. In another work, Cyr et al. (2007) argue that online shopping experiences lack human warmth as they are more impersonal, anonymous and do not provide face-to-face communication. They investigated how loyalty is influenced by social presence and if there are gender differences. Five e-Commerce web sites with different interactive elements were created and customers had to browse one of the websites and buy concert tickets. The results indicate that social presence influences loyalty as well as enjoyment, but that there are differences between males and females. For example, the direct impact of social presence on loyalty could only be shown for females but not for males. In Itchy Feet the social presence is achieved through the 3D Virtual World which implicitly addresses social interaction. Just as in the real world, a user can see other users, is able to walk towards them and can start talking to them. It is fairly easy to get in touch with other people and new relationships can emerge quickly. Thus, 3D Virtual Worlds should help to increase the social presence and might have a positive influence on the enjoyment, loyalty and trust of users towards the environment.

Agent Technology

An interface determines how users are able to access and view the data in a system. The actual internal representation and structure of this data can be achieved by various means. Multi-Agent Systems are one possibility and have already been employed in the tourism domain for information gathering, representation and aggregation. For example, Chiu and Leung (2005) designed a virtual enterprise of independent tourism service providers as a Multi-Agent System. Agents make use of Semantic Web concepts to improve the planning stage and help customers in understanding and specifying their requirements and preferences. The authors' motivation was the lack of tourist portals that proactively assist tourists by adequately integrating disparate information sources and services. The Multi-Agent System developed by Chiu and Leung (2005) addresses these issues to create a ubiquitous tourist assistance system. A similar approach, that also relies on agent technology to retrieve tourist information from distributed databases, was presented by Yeung et al. (1998). A customer can use the system through a special interactive graphical user interface that allows the user to enter search queries and to trace the information search and retrieval. In the background the information requests are processed by different types of software agents which communicate via the Knowledge Query and Manipulation Language (KQML) (Finin et al., 1994). Typically, a search request is passed to a specific information agent that has knowledge about the search topic. The information agent then queries a database and the result is sent back to the requesting agent. Special attention was paid to platform independence - all system components are either implemented in Java or other platform independent technologies and KQML is used as a platform independent communication protocol. In Itchy Feet, software agents are also used to provide access to tourism knowledge. They are the entities upon which the business processes are realized and they facilitate the integration of tourism data within the 3D Virtual World. For example, the integration of the forum in the 3D Virtual World is realized by means of software agents. The forum itself is a public Web forum that is accessed by the software agents which aggregate the data and provide them within the 3D Virtual World. Furthermore, the software agents enable users to participate in this Web forum directly from within the 3D Virtual World. The users are able to create new posts and threads which are submitted to the Web forum via the software agents.

The implementation of software agents usually follows a specific methodology aimed at defining the way agents need to be modeled. Several formal methodologies have been proposed in the literature of which some are exemplarily presented in the following. Dignum and Dignum (2001) introduced a formal methodology for the development of agent societies. They divide the requirements into functional and interaction requirements. Functional requirements define what a system is supposed to do and interaction requirements define how the system is supposed to do it. In a subsequent work a methodology for the design of agent societies based on the type of coordination structure was presented (Dignum et al., 2002). Gaia, a methodology for agent-oriented analysis and design was introduced by Zambonelli et al. (2003). It was the first formal methodology specifically developed for agent-based systems. The approach is based on designing a Multi-Agent System as a computational organization. Furthermore, the methodology was extended for the analysis and design of Multi-Agent Systems. Clear guidelines for analysis and design are provided by Gaia.

In Itchy Feet we build upon the Electronic Institution methodology (Esteva et al., 2001). This methodology was developed for modeling agent organizations effectively as institutionalized electronic organizations. The methodology is based on the notion of real world institutions. In the real world, institutions represent the framework within which human interaction takes place including the restrictions and permitted actions. Such definitions are mapped onto Electronic Institutions which are the electronic counterpart of real world institutions. Electronic Institutions are populated by heterogeneous software agents and humans that interact by means of speech acts. In Itchy Feet Electronic Institutions are employed to ensure trust among the participants of the environment. They define the regulatory framework upon which all actions are executed and verify that all the participants adhere to the specified rules.

Multi-Agent Systems and 3D Virtual Worlds

Some works report on the combination of Multi-Agent Systems and 3D Virtual Worlds. Smith et al. (2003) present an approach where the agent logic is incorporated in a 3D environment. According to the authors most worlds are largely static and objects are used to trigger pre-programmed behavior. Agents are supposed to enrich the world and should make the environment more dynamic. The proposed framework consists of a society of agents in which each agent controls a 3D object. As an example, a conference room consisting of wall agents and a room agent is presented. Depending on the number of avatars in the room, the agents react and dynamically adapt the room size. In the case of Itchy Feet the 3D Virtual World is also populated by agents that are visualized as avatars and make the environment more lively and dynamic.

Adobbati et al. (2002) presented GameBots; a system that abstracts from the Multi-Agent System and provides a uniform interface to the 3D Virtual World. They created a multi agent research test bed that is not limited to a specific task in a fixed environment and supports human testing and interaction. The GameBots environment enables human participation, is easily customizable (due to a scripting language), and supports multiple environments and tasks. The Unreal Tournament Semi-Automated Force (UTSAF) project takes advantage of GameBots (Manojlovich et al., 2003). It is a framework that connects military simulations with a 3D visualization. The goal is to create a system that scales well on large and heterogeneous simulation environments. To this end, they developed a framework in which an agent system is used as the mediator between the military simulation and the 3D Virtual World. Agents monitor the status of the military simulation, filter relevant information and visualize entities of the simulation in a 3D Virtual World. In the same manner as agents are used to extract and present information in UTSAF, Itchy Feet also utilizes agents to aggregate and present tourism information in the 3D Virtual World.

In the following, works are presented that take advantage of 3D Virtual Worlds for modeling interactions between humans and agents. This is similar to our approach in Itchy Feet where the 3D Virtual World is inhabited by humans as well as software agents and the 3D Virtual World facilitates the interaction between these two parties. Nakanishi and Ishida (2004) developed a social interaction platform named FreeWalk/Q where software agents and human controlled avatars share the same environment, interaction model and scenario. They introduced different topologies and description levels to describe the behavior of agents and human avatars enabling the integration of both parties into the virtual environment. Face-to-face communication in 3D worlds is addressed by Traum and Rickel (2002). They concentrate on issues such as proximity and attentional focus of others, the interplay between speech and nonverbal signals and the ability to maintain multipart conversations. They introduced an example scenario to demonstrate an initial implementation of their model. A similar approach to seamlessly integrate agents and humans in a cohesive Multi-Agent System was introduced by Martin et al. (2003). In their work they describe a software prototype of a distributed collaboration and interaction system helping humans to act as an integrated part of a Multi-Agent System. They introduced so-called liaison agents which support human interaction with other non-human agents by arbitrating between them. Payne et al. (2000) analyzed human-agent interaction and stated that agents can have different models of user interaction. In their work they describe a case study of a Multi-Agent System containing different agents, with some having functionally similar capabilities, but with different types of user interaction modalities. They argue that according to the type of user interaction a significant effect on the performance of the whole agent community can be ascertained.

Electronic Institutions

The Multi-Agent System methodology employed in our work is referred to as Electronic Institutions (EI) (Esteva et al., 2001). The idea underlying Electronic Institutions is to apply the concept of real world institutions to Multi-Agent Systems. An Electronic Institution defines rules and norms for the interaction and behavior of agents. It specifies the actions an agent can perform in the current state of the institution and how the agent can move within the institution. The key elements of an Electronic Institution are scenes and transitions. A scene is composed of a state automaton describing the actions that may be executed by an agent in a specific state. These scenes are interconnected with each other through transitions. A transition restricts the movements of an agent within the institution. The composition of scenes and transitions forms the layout of an Electronic Institution and is referred to as performative structure. Another element of Electronic Institutions are roles. During system execution every agent plays a specific role at every point in time. The role type defines the type of actions that an agent may perform and defines how an agent may move between scenes.

These concepts are illustrated by example in the following. Figure 4.3 shows a simplified version of the performative structure of the Travel Agency Electronic Institution (upon which the Travel Agency is realized in the 3D Virtual World (cf. Figure 4.1)). It is composed of six different types of scenes that are interconnected with each other through transitions. The direction of the transitions indicates the possible movement between the scenes. The role names indicate which role is allowed to pass through which transition. In this example, three different roles are highlighted: the user, the employee and the account manager. The user and employee role are played by humans while the account manager role is played by an autonomous agent. The Electronic Institution is entered through the entry scene and exited through the exit scene. The information scene provides search facilities for finding accommodations which can then be booked in the booking scene and paid in the payment scene. In the sale scene, the user is able to talk to a travel agent and can get help with personal requests from a professional of the travel industry. There are multiple instances of sale scenes, meaning that multiple travel agents might be available in different sale scenes at the same time. The scene protocol, which is shown in the lower right part of Figure 4.3, illustrates the state automaton of the payment scene. There are three different states: entry, payment and exit. The scene can be entered by the user and account manager role in the entry state. However, only the account manager is able to start the scene by issuing a *startScene* message. The scene then evolves to the payment state in which users are able to enter and exit the scene. As long as the Travel Agency is opened in the 3D Virtual World, the scene remains in the payment state and users are able to access the services by entering the scene in this state. The user is able to pay a product and to return a product in the payment state. In the latter case the user sends out a *passBackProduct* message to the account manager which either sends back a *productAccepted* message if the product could be returned successfully or a *productDenied* message if the product could not be returned. In the case of the payment, the user sends out a *payForProduct* message to the account manager which responds with a *transferOwnerShip* message if the payment was successful. The scene can be closed through the account manager by issuing a *closeScene* message. The scene then evolves to the exit state in which the scene can be left by the account manager and the user. When the scene is closed, the services are no longer accessible to the users.

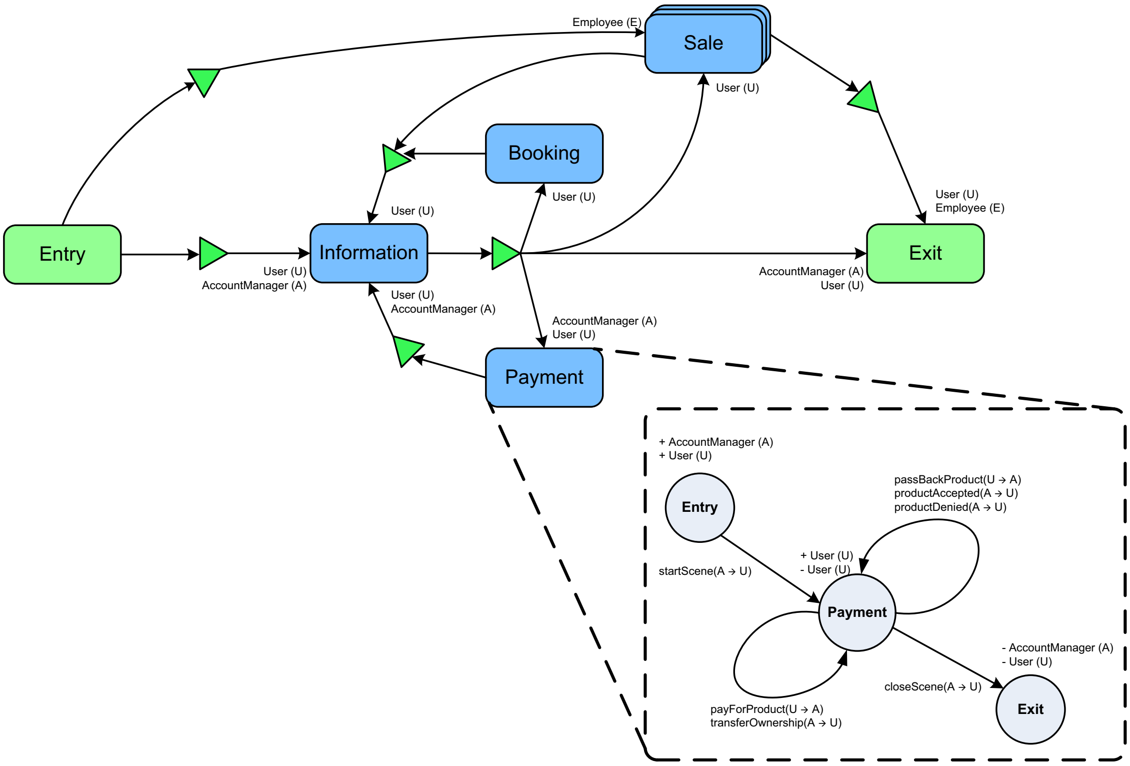

Figure 4.3: A simplified representation of the performative structure and the scene protocol of the Travel Agency Electronic Institution.

The engineering of Electronic Institutions is supported by the Electronic Institution Development Environment (EIDE)[1]. This framework includes tools that allow designers and programmers to specify, implement, verify and actually run Electronic Institutions (Arcos et al., 2005). The two essential tools to create a custom Electronic Institution are *Islander* and *Ameli*. Islander supports the creation of Electronic Institution specifications (Esteva et al., 2002) and Ameli is used to execute Electronic Institutions (Esteva et al., 2004). Islander offers a graphical editor in which the layout of the Electronic Institution, the structure of scenes and the role hierarchy can be specified. The output of the program is an XML document containing specifications of all components of an Electronic Institution. These specifications are used as input to the runtime environment Ameli which executes the Electronic Institutions and controls the behavior of all participating agents. Ameli may execute several Electronic Institutions at the same time and validates all agent actions according to the Electronic Institution specifications.

[1]http://e-institutor.iiia.csic.es/ (last accessed 02.05.2010)

Virtual Institutions

The concept of combining Electronic Institutions with 3D Virtual Worlds was introduced by Bogdanovych et al. (2005a). It is known as 3D Electronic Institutions and was further generalized towards Virtual Institutions. In this paper the authors point out that the relationship between humans and software agents did not receive much attention in research yet. 3D Virtual Worlds are proposed as an interface that enables human users to communicate with software agents and to strengthen the relationship between humans and software agents. Humans and agents learn from each other. The agent learns about the behavior of the user and the user learns about the structure and rules of the Electronic Institution. The e-Commerce domain is mentioned as a promising application domain for 3D Electronic Institution which is then further explored in (Bogdanovych et al., 2005b; Debenham and Simoff, 2006; Berger et al., 2006). In (Bogdanovych et al., 2005b) an in-depth description of the three layered system architecture that connects 3D Virtual Worlds and Electronic Institutions is given. The authors illustrate how they used the Adobe Atmosphere player to create the 3D Virtual World and how the connection with the Electronic Institution is accomplished. The importance of the social aspect in e-Commerce is stressed and 3D Virtual Worlds are proposed as an alternative interface that retains the social warmth of real world commerce to a certain degree. Debenham and Simoff (2006) present an e-Market framework for informed trading which is based on three core technologies: data mining, trading agents and Virtual Institutions. A data mining system is presented that enables agents to extract data in real time from external sources as well as from the negotiation process during the negotiation with other agents. Trading agents then operate on the extracted data and are capable to perform automated trading based on this real time data. Virtual Institutions are utilized as the regulatory environment in which the agent interaction takes place and further enable the participation of human users in the e-Market. The believability of e-Market places is addressed by Debenham and Simoff (2009). They identified four believability components (believability of regulations, processes, spaces and interactions) that are necessary to create a believable e-Market place and developed a web based prototype to showcase this marketplace. Virtual Institutions are extended to enable the creation of believable marketplaces and a formal model is proposed to capture the notion of believability. A predecessor of the Itchy Feet project is presented by Berger et al. (2006). This paper explores 3D Electronic Institutions from a game and community perspective. The role model of MMORPGs is applied to an e-Business environment and it is shown how the 3D Virtual World can act as a community facilitator to create and establish a lively community of customers. A first concept of a 3D e-Tourism environment is presented which later evolved into the Itchy Feet project. This concept is further elaborated in (Berger et al., 2007) where a detailed showcase in the tourism domain is presented, the general architecture is introduced and the further development roadmap is discussed. As outlined in Section 1.3, the technological framework of Itchy Feet was then presented in (Seidel and Berger, 2007), the business processes on the agent level were introduced in (Gärtner et al., 2008), the e-Tourism environment was showcased in (Seidel et al., 2009b) and the market mechanisms of Itchy Feet were addressed in (Seidel et al., 2009a).

In his PhD thesis Bogdanovych (2007) further explored the concept of Virtual Institutions as normative 3D environments in which human and software agents are able to participate. A methodology for the development of 3D Electronic Institution is proposed which consists of five steps (Bogdanovych et al., 2007). In the specification step the normative environment is specified on the Electronic Institution level. In the verification step the normative design is verified for correctness with respect to the formal framework of Electronic Institutions. The buildings in the 3D Virtual World are then created automatically in the generation step based on the layout of the scenes in the Electronic Institution specification. The annotation step enables the developer to additionally define the connection between the Electronic Institution specification and the 3D Virtual World. The 3D content within the rooms and additional cues such as the placement of doors can be specified in the annotation editor which is an extension to the Islander editor. Finally, in the integration step, the mapping between the messages in the Electronic Institution and the actions in the 3D Virtual World are defined. In contrast to our work, the 3D content is generated automatically in this methodology, while we focus on the manual creation of the 3D Virtual World. The manual creation is sufficient in our case as we strive to create one specific 3D Virtual World which is then evaluated with end users in order to investigate what forms 3D Electronic Institutions might take. The automatic generation, as part of the methodology, is the subject of another work by Bogdanovych and Drago (2006) in which they present an algorithm for the automatic transformation of the performative structure into a floor plan. The scenes and transitions of the performative structure are transformed to rooms that lie next to each other. Any planar performative structure graph can be transformed into a 3D Virtual World representation with this algorithm. Trescak et al. (2009) also work on the automatic generation of floor plans for the 3D Virtual World. Their approach is based on shape grammars. Shape grammars are geometric rules that define how a part of a design can be transformed. Starting with a set of basic shapes, these rules are applied in an iterative fashion and new and more complex designs start to emerge. Trescak et al. (2009) developed the shape grammar interpreter which is a framework for the definition of shape grammars that also enables the designer to take part in the design process. This tool is then extended and utilized for the creation of floor plans and 3D Virtual World designs in a subsequent work (Trescak et al., 2010). In this work, the concept of virtual world grammars is introduced. A virtual world grammar extends the geometric information of shape grammars with semantic information about the Electronic Institution specification and grammar elements in order to enable the generation of complete Virtual Institutions.

The methodology was also used for the creation of a Virtual Institutions prototype (Bogdanovych et al., 2009b) upon which a cultural heritage application was developed (Bogdanovych et al., 2009a). The ancient city of Uruk was rebuild in Second Life and the daily routines of two fishermen families were specified via Electronic Institutions and visualized in the 3D Virtual World. Every inhabitant is represented as an agent in the Electronic Institution and plays a certain role (e.g. boatowner, firekeeper). The role determines the activities that the agent performs throughout the day. Human users are able to observe the city, to participate as a visitor or to slip into the role of an inhabitant. When the user participates in the visitor role, she can move around freely in the environment and talk to the agents. In contrast, when participating as an inhabitant, the user has to act according to the routines specified in the Electronic Institution. Rodriguez et al. (2008) extend Virtual Institutions with intelligent objects (iObjects) in order to facilitate the participation of human users. Intelligent objects are composed of sensors, a decision module and effectors. They are capable of sensing changes in the 3D Virtual World (e.g. avatar interactions, avatar movement) as well as changes in the Ameli system (e.g. state change in a scene). The decision module is responsible for processing these actions and events and if they have an effect on the environment, the environment (3D Virtual World as well as Ameli) is changed through the effectors. There are two types of iObjects: iObjects on the institution level and iObjects on the participant level. The first type includes objects that are added to the 3D Virtual World (e.g. doors and rooms), while the second type of objects captures personal information about the users. These objects are displayed on the 2D user interface and they include information on the user's obligations, the information model and the history of user participation.

4.3 A Framework for 3D e-Commerce Environments

The presented related works on e-Commerce and e-Tourism showed that 3D Virtual Worlds are a promising environment for the provision of e-Commerce and e-Tourism services. The familiarity of a spatial 3D environment should help to increase the perceived social presence and human warmth of electronically provided services. Furthermore, social interaction is addressed implicitly in these environments and communities as a constituent part of 3D Virtual Worlds additionally provide opportunities for tourism. Tourists are able to share their knowledge within the community, to discuss tourism related topics and to query travel experts with personal requests. Virtual Institutions can be employed to ensure trust among the participants and as an infrastructure upon which the business processes and information retrieval facilitates are implemented. They were identified as a promising framework for the implementation of e-Commerce and e-Tourism platforms. However, the practical implications have not yet been empirically studied with actual end users, due to the lack of suitable prototypes. This problem is addressed through the creation of a Virtual Institution based 3D e-Commerce framework which will be presented in the following.

Conceptual Design

In the 3D e-Commerce environment two types of participants need to be considered: humans and agents. Agents are either autonomous or controlled by a human user. In the latter case, the couple human/agent is represented as an avatar in the 3D Virtual World. Humans and agents learn from each other and work together to collaboratively achieve certain goals. The user delegates tasks such as information gathering or product purchasing to the agent and learns from the agent which rules and restrictions apply in the environment. The user must act according to these rules. The movement and actions of the user in the 3D Virtual World are verified by the agent in the Electronic Institution.

Autonomous agents must be visualized in the 3D Virtual World such that users are able to interact with them and to learn from them. An autonomous agent is a software agent that is capable of reacting to its environment and proactively makes its decisions based on the input from the environment and its internal decision model. The visualization of autonomous agents depends on their task. For example, an agent that actively participates in conversations may be visualized as a human-like avatar, whereas a simple information agent may be visualized as an information monitor.

The dependence between the two systems requires that the 3D Virtual World is causally connected to the Electronic Institution. Causality refers to properties of the connection between a system and its representation (Maes and Nardi, 1988). In our case this means that whenever the 3D Virtual World changes, the Electronic Institution must change as well. Whenever the Electronic Institution evolves, the 3D Virtual World has to be modified in order to maintain a consistent relationship. Thus, whenever a visualized agent moves around in the Electronic Institution or changes its state, the 3D Virtual World must reflect this change (e.g. update the information monitor, reposition the avatar).

And, conversely, whenever the user moves around or performs an action in the 3D Virtual World, the user's agent must perform this action in the Electronic Institution (e.g. move from one scene to another, send out a scene message). Inconsistencies are resolved by the 3D Virtual World. In the case that the state in the Electronic Institution and the state in the 3D Virtual World are inconsistent, the 3D Virtual World is adapted to restore a consistent relationship. This approach results from the fact that the Electronic Institution is the regulatory environment and defines the correctness of a state. As an example consider the situation in which an user slips through an open door in the 3D Virtual World although she is not supposed to enter this room. The user's agent will then try to enter the respective entity in the Electronic Institution, but will not be allowed to do so. As a consequence, the Electronic Institution and the 3D Virtual World are in an inconsistent state. This conflict is resolved in the 3D Virtual World by teleporting the user's avatar back to the previous room. The system and its representation are then in a consistent state again. In order to implement this causal connection, the system is composed of three layers whereof the 3D Virtual World is located at the top layer, the Electronic Institution is located at the bottom layer and both components are causally connected by the middleware layer.

The Framework Architecture

An overview of the architecture is depicted in Figure 4.4. The rectangles define self-contained execution environments in which each application is running. These environments may run on the same computer or can be distributed across several machines. The communication between the layers is based on the TCP protocol. The components within each layer listen to network traffic and send messages on predefined ports.

The Administration Tool is connected to the data store and used for the administration of the components on every layer. The Electronic Institutions, the middleware as well as the Torque server can be started and stopped. Remember that the Torque game engine is used to realize the 3D Virtual World (cf. Section 2.3). The configuration is based on XML files that can be manipulated and managed via the Administration Tool. The connection to the data store enables administrators to create, manage and delete data that is used in the framework. There are generally two types of data: generic data that is used in every 3D e-Commerce environment and domain specific data which is only used in the context of the application domain. Examples of generic data are login data or user account data while examples of domain specific data could be flight or hotel data.

The bottom layer contains Ameli, the Electronic Institution runtime environment. The TCP port of the Ameli component is used to send all events that occur in the Electronic

Institutions to the middleware. This also includes the actions of autonomous agents that run the Electronic Institutions. Depending on their roles, these agents have access to the data store and can access registration information, user profiles or domain specific data. The Remote Server is responsible for the message exchange with external agents allowing them to participate in the Ameli system. A predefined communication protocol (which is specified in the Electronic Institutions Development Environment) enables the communication with external agents. External agents send action requests to the Remote Server which are then validated in the Ameli system according to the Electronic Institution specification. The Remote Server returns reply messages to the external agent.

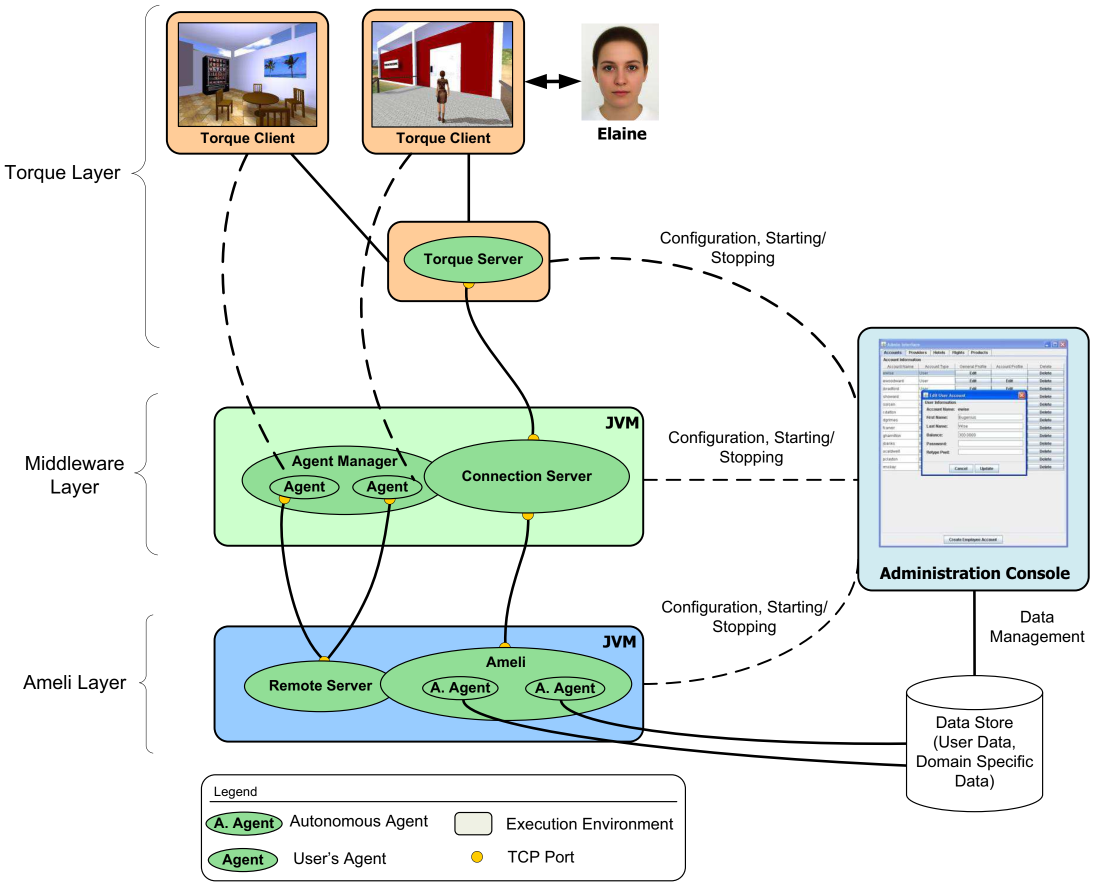

Figure 4.4: An overview of the framework for connecting Electronic Institutions with 3D Virtual Worlds.

Torque is running on the top layer following a client/server architecture. The server is running in dedicated mode controlling the state of the 3D Virtual World and observing the actions of the users. The server guarantees a consistent relationship with the Ameli system and changes the state of the 3D Virtual World if necessary. The connection between the Torque server and the middleware is used to exchange messages between these two layers. The Torque client runs on the user's computer and is used to visualize the 3D Virtual World. When the client is started, a connection to the Torque server is established. The server and client run in different execution environments and may be distributed across several machines. In Figure 4.4, we can see that a user named Elaine has started the client and entered the 3D Virtual World with her avatar.

The middleware connects the upper layer with the lower layer. The connection to the Ameli system is used to listen to events that occur in this system and to enable the participation of user agents. The connection with the Torque layer is used to exchange messages with the Torque system. The users' agents are managed by the Agent Manager component. Every user in the 3D Virtual World is the principal of an agent in the Agent Manager. The connection between Elaine and her agent is depicted with a dotted line between the Torque client and the agent in Figure 4.4. Action requests from the user are sent to the middleware and forwarded to the user's agent in the Agent Manager component. These agents act as external agents and communicate with the Ameli system through the Remote Server.

Connecting Electronic Institutions with 3D Virtual Worlds

To generate a mapping between entities of the 3D Virtual World and the Electronic Institution, two steps need to be carried out. First, a floor plan that specifies the layout of rooms and doors in the 3D Virtual World must be created. Second, the rooms and doors need to be linked to the entities of the Electronic Institution (scenes and transitions). In a straightforward approach scenes are mapped onto rooms and transitions are mapped onto doors. This is illustrated in Figure 4.5 where the scenes of an Auction Electronic Institution are directly mapped onto rooms in the 3D Virtual World: the Information Scene is mapped onto the information room, the auction scene onto the auction room and the clearing scene onto the clearing room. If two scenes are connected in the Auction Electronic Institution, the corresponding rooms are connected by a door.

The 3D Virtual World in Figure 4.5 is populated by five avatars of which four are visual representations of autonomous agents and one avatar is controlled by Elaine. The relationship between agents in the Electronic Institution and the avatars in the 3D Virtual World is illustrated by the symbols underneath each avatar. For example, the autonomous agent in the auction scene is visualized by the avatar standing in the auction room. The figure also includes two exemplary message exchanges between the 3D Virtual World and the Electronic Institution. These are explained in more detail in the next Section.

The relationship between the entities of the Electronic Institution and the 3D Virtual World is defined in a mapping specification. Such a specification contains the following elements: the Scene-Room relationship specifies which scene is mapped onto which room, the Transition-Door relationship specifies which transition is mapped onto which door and the Role-Avatar relationship specifies visual cues for agent roles. A visual cue helps to visually identify the duties of a certain avatar. For example, the role of a sale agent might require the avatar to wear a specific work dress. The user is then able to easily identify a sales agent in the virtual world. The mapping must be provided for each Electronic Institution individually and is defined in an XML document. This document is parsed by the Torque server in order to trigger the appropriate actions when a user moves between rooms. Furthermore, the Torque server uses the mapping information to appropriately visualize autonomous agents.

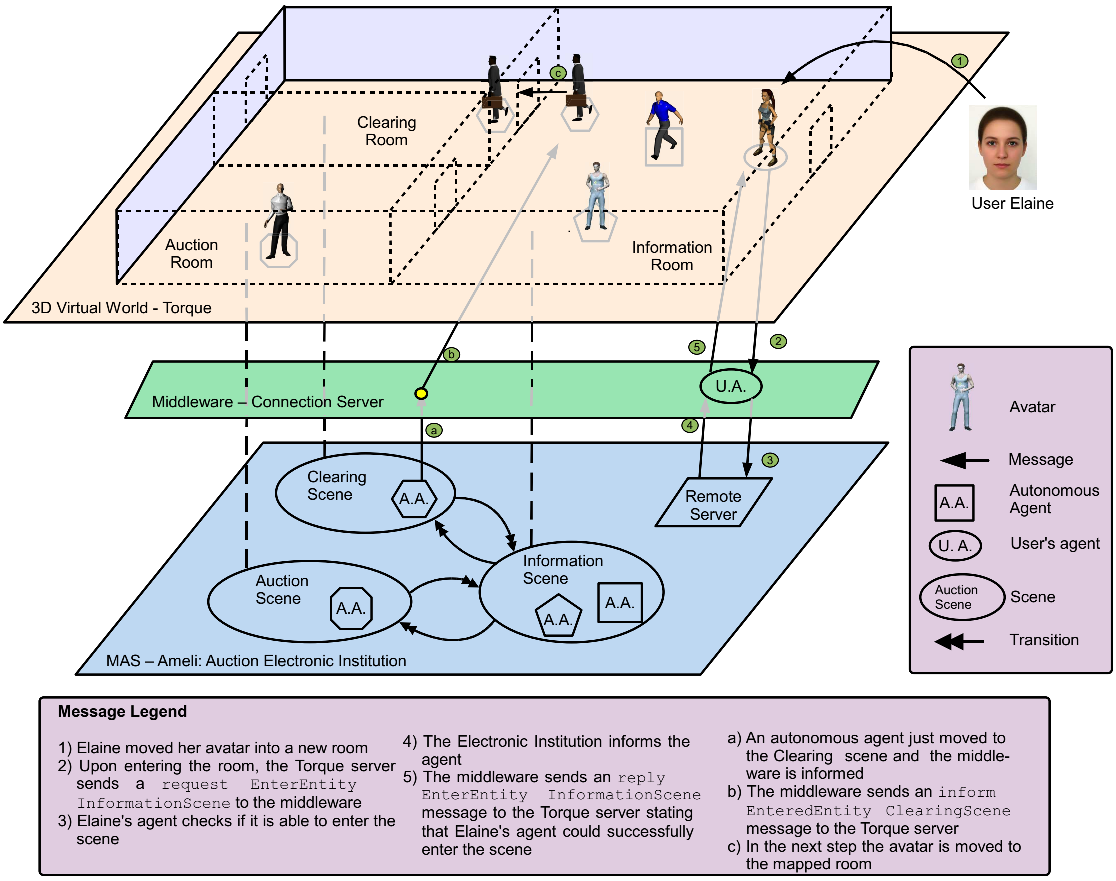

Figure 4.5: The interplay of the components in the framework.

Message Protocol

Messages that are exchanged between the 3D Virtual World and the middleware layer are defined in a message protocol. These messages are organized in three different categories.

Status messages are used to query Ameli about the current state of the system. Action messages are sent whenever an action takes place in the 3D Virtual World or in the Ameli system. Error messages are used to indicate a failure. The message protocol is based on the following basic message types:

- request (request an action to be performed, request information)
- response (successful response to a request)
- error (error message, used as response to unsuccessful requests)
- inform (information message, inform the other part, no response is expected)

Messages contain a header and a content section. The header identifies the recipient in order to ensure appropriate delivery of the message. The content section holds the actual information. In general, the majority of the messages in the message protocol correspond to an event that may occur in the Ameli system. The messages are used to abstract the events and to extract and forward only the relevant parts of each event. For example, if an autonomous agent enters a scene, the event `EnteredSceneEvent` occurs in Ameli. The middleware is notified that this event has happened and informs the 3D Virtual World with an `inform` `EnteredEntity` `Scene` message. The message protocol is implemented in XML and the XML representation of an `EnteredEntity` message is shown in Listing 4.1.

Listing 4.1: XML representation of an `EnteredEntity` message which is sent between the middleware and the 3D Virtual World

```
<CS3DMessage id="32">
  <header>
    <particle>inform</particle>
    <platform>ItchyFeet</platform>
    <federation>ItchyFeet-Federation</federation>
    <ei>AuctionHouse</ei>
  </header>
  <content>
    <EnteredEntity direction="cs-3d">
      <entityType>scene</entityType>
      <name>InformationScene</name>
      <avatarid>Auctioneer</avatarid>
    </EnteredEntity>
  </content>
</CS3DMessage>
```

The communication between the middleware and the 3D Virtual World can be split into two different types of communication patterns.

First, the actions of autonomous agents must be visualized in the 3D Virtual World. To this end, the message protocol contains messages that are used to inform the 3D Virtual World about the movement or actions of agents. Examples of such messages are the different instances of `EnteredEntity` messages. They are used whenever an autonomous agent entered a certain entity in the Ameli system and the mapped avatar must perform a movement in the 3D Virtual World. In the case of an `inform EnteredEntity Scene` message, the autonomous agent entered a new scene and, as a consequence, the corresponding avatar must be moved to the mapped room in the 3D Virtual World. Whenever this message is received, the 3D Virtual World looks up in which room the scene is visualized and moves the avatar to the corresponding room. An example of such a message exchange is shown in Figure 4.5 (messages a-c). In this example an autonomous agent has just entered the clearing scene. The Ameli system sends out a message to the middleware layer (message a) which is forwarded to the corresponding avatar in the 3D Virtual World (message b). As a consequence, the avatar must be moved from the information room to the clearing room (message c).

Second, action requests of users must be validated in the Ameli system. Whenever a user performs an action in the 3D Virtual World, this action must be verified by her agent in the Ameli system. This communication consists of a request and a response message. Figure 4.5 exemplifies the use of these message types (messages 1-5). We can see that Elaine has just entered the information room in the 3D Virtual World (message 1). Her corresponding agent also referred to as controlled agent must now move to the mapped scene in the Electronic Institution. For this reason a `request EnterEntity InformationScene` message is sent to the middleware (message 2). Elaine's controlled agent forwards the request to the Ameli layer where the agent tries to enter the Information Scene (message 3). The response is then sent to the agent (message 4) and forwarded to the 3D Virtual World by the agent (message 5). If the agent could enter the scene the Ameli system reflects the same state as the 3D Virtual World. However, if the agent could not enter the scene, Elaine must leave the room in order to guarantee the consistent relationship between the system and its representation. This is resolved by teleporting the user out of the room.

The Ether Electronic Institution

The management of users in the framework is accomplished by a dedicated Electronic Institution called Ether Electronic Institution. The Ether Electronic Institution is some-what special, because it does not have a visual representation like the other Electronic Institutions in the framework. Services in the Ether Electronic Institution are accessible independent of a user's current location in the 3D Virtual World. The name is derived from the physical concept of Ether, a term used in ancient science to describe a medium that propagates light. The Ether was thought to be a substance above the clouds extending everywhere in space. In a similar manner, the Ether in our framework can be thought of as a medium that occupies every point in the 3D Virtual World.

In its general form, the Ether Electronic Institution provides services for user registration, user management and user login. Depending on the application domain of the 3D e-Commerce environment, additional functionalities can be added to the Ether Electronic Institution. For example, in a shopping related environment, the functionality of a shopping cart might be realized in the Ether Electronic Institution.

Framework and User Administration

The execution of the framework is controlled via the framework manager application (illustrated in Figure 4.6). The framework manager is the control center for the execution of the different components and provides an overview on the current status of each component. There are five different components which are required to execute the whole framework. They are:

1. **The Database:** the persistent data store holding information such as user profiles and account data

2. **The Connection Server:** the middleware layer between the 3D Virtual World and the Multi-Agent System

3. **The Multi-Agent System:** the runtime environment for the Electronic Institutions

4. **The 3D Server:** the dedicated server which executes the 3D Virtual World

5. **The 3D Client:** the client application with which the user connects to the 3D Server

These components have to be started in the given order. The database is launched first, followed by the Connection Server which sets up communication end points for the Multi-Agent System and the 3D Server. The Multi-Agent System is started next, a connection to the Connection Server is established and the software agents are initialized. The 3D Server then also establishes a connection to the Connection Server, retrieves the initial state of the Multi-Agent System and visualizes the current state of the Multi-Agent

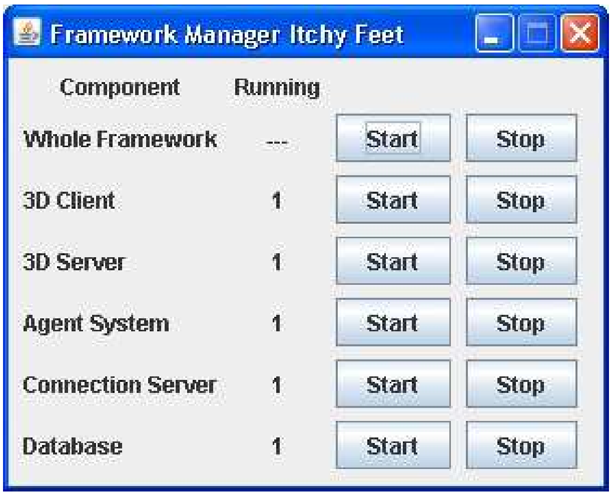

Figure 4.6: The framework manager.

System in the 3D Virtual World. Users are then able to connect to the framework by using the 3D Client which establishes a connection to the 3D Server.

The administration of the framework can further be controlled by an administration tool. This tool enables administrators to configure the system and to manipulate user accounts - i.e. user accounts can be created, modified and deleted. The administration interface of Itchy Feet is depicted in Figure 4.7. It contains a management for user accounts and was extended by numerous other functions to enable the manipulation of the domain specific data of Itchy Feet. The interplay of the interface with the other system components is shown in Figure 4.4.

4.4 A Detailed Look at Itchy Feet

The generic e-Commerce framework that was presented in the previous Section was applied to the tourism domain to create the 3D e-Tourism environment Itchy Feet. The environment comprises four different Electronic Institutions in which the business processes are defined and the interactions between agents and humans takes place. In the Ether Electronic Institution agents provide registration and account management facilities. The Travel Agency Electronic Institution contains agents that enable the search for fixed price products and offers booking and payment services. In the Auction House Electronic Institution auctions are conducted by agents and payment services are provided. The Forum Electronic Institution includes agents that provides access to an external Web forum. The features and mechanisms of Itchy Feet as well as the participation in Itchy Feet from a user's point of view are presented in the following.

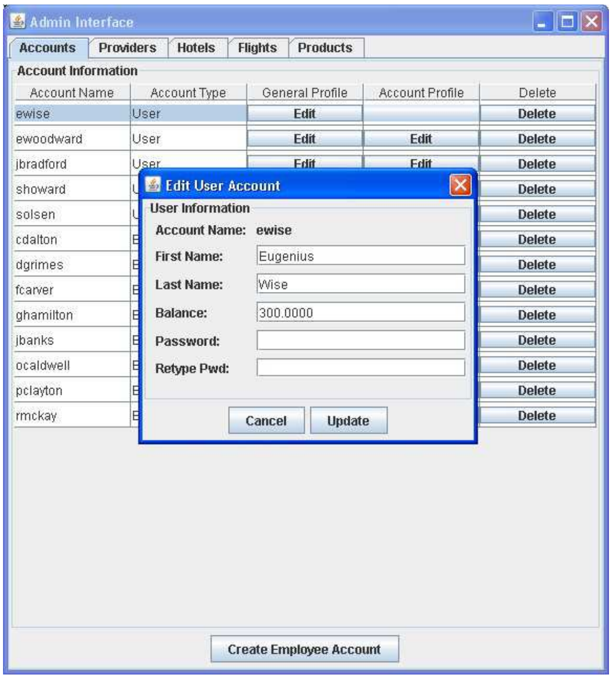

Figure 4.7: The administration interface.

Role Policies in Itchy Feet

Access control in Itchy Feet is realized via roles. Every Electronic Institution specifies a set of agent roles that define the access policy to this Electronic Institution and to the scenes within the Electronic Institution. For security reasons it needs to be ensured that agents playing in certain roles, such as the *User* role, may not have access to all scenes of an Electronic Institution. The agent roles in Itchy Feet are divided into three groups: *Staff* roles, *Consumer* roles and *Employee* roles. These roles and their relationships are depicted in Figure 4.8. *Staff* roles are solely played by autonomous agents whereas *Consumer* roles and *Employee* roles can be played by autonomous agents as well as user controlled agents. Agents playing in a *Staff* role provide services to *Consumer* agents.

The *Consumer* group contains one specific role at the moment, namely the *User* role. A user's controlled agent always plays in the *User* role. Note that the term *User* printed italic refers to the role in the Electronic Institution that can be played by a software agent as well as a human user. In contrast, the term "user" refers to an actual human user that is participating in Itchy Feet via the 3D Virtual World. The *Employee* group is extensible and every provider in the environment is able to define roles in this group. Agents and users who are playing in these roles act on behalf of the organization and provide services to *Consumers*.

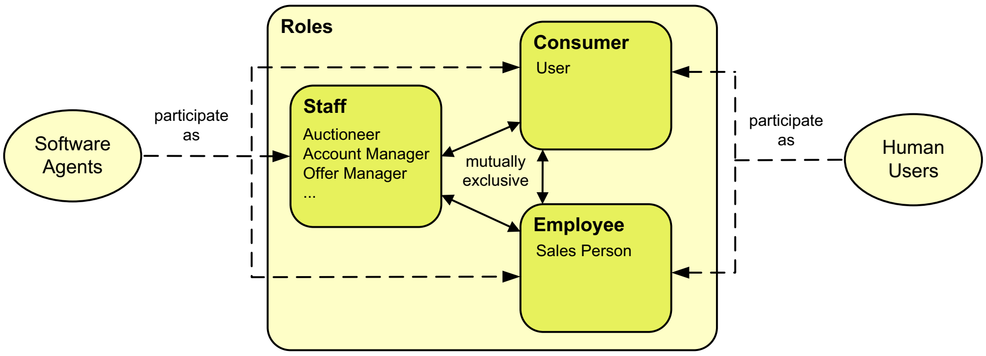

Figure 4.8: Role policies in Itchy Feet

The 3D Virtual World

The 3D Virtual World of Itchy Feet provides a visual representation of the presented Electronic Institutions. Except for the Ether Electronic Institution, the functionality of an Electronic Institution is within the scope of a building in the 3D Virtual World. Auctions can be performed in the Auction House, information gathering and product trade take place in the Travel Agency and participation in the forum is possible in the Forum building. The buildings have entry and exit doors and contain rooms that are connected via doors.

The Forum building contains one room, since all the functionality of the Forum Electronic Institution is provided in one scene. In this room, the user can launch a 2D forum interface and is able to browse the forum, create posts and start new threads. The forum interface is displayed in Figure 4.9. Elaine has started the forum interface and is currently showing the “Car rental in Romania” thread. She can engage in the conversation by entering a new message in the message box at the bottom of the list. Furthermore, the 3D Virtual World opens the possibility to project the most recent discussions onto walls where they can be read and followed by multiple users simultaneously.

The Auction House contains four rooms: an information room, two auction rooms and a clearing room. In the information room upcoming auctions are displayed, the two auction rooms are used to conduct auctions and in the clearing room products are paid. A user participates in an auction by entering a bid into an input box. The current state of the auction is broadcast to all participants and displayed on the user’s interface. When a user wins an auction, the product is placed in her shopping cart and has to be paid in the clearing room. The payment information is entered via a 2D input mask. As soon as the product was paid, it is transferred to the user’s inventory.

In the Travel Agency information facilities are available and the trade of fixed price products takes place. The building consists of four rooms whereof three rooms are Sale

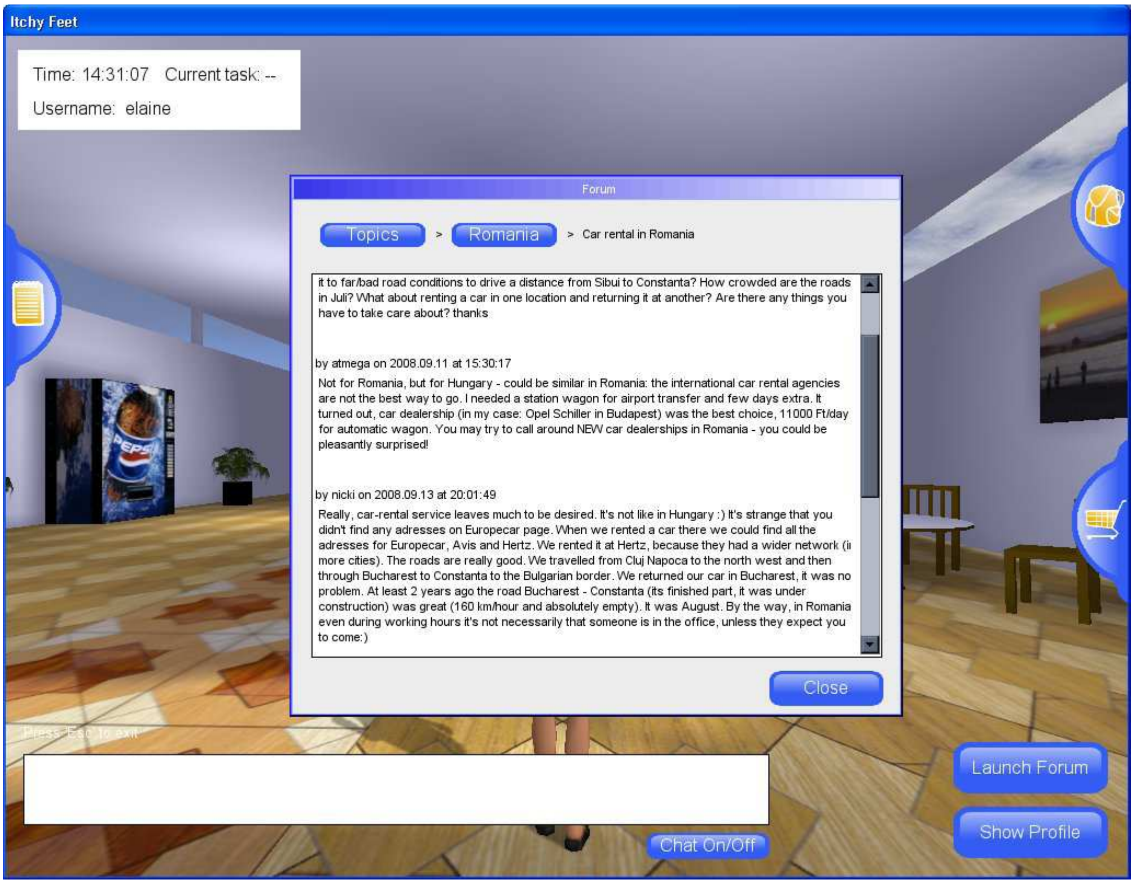

Figure 4.9: The forum interface.

rooms and one room is the main information room. In the Sale rooms, users can get professional help from travel agents that are also logged in the 3D Virtual World and are represented as avatars. Similar to a travel agency, a user can directly interact with another human being, ask specific questions and let the travel agent take care of the booking. In the main information room, the user is able to search for tourism products. The search facilities are 2D interfaces in which the query is entered and the aggregated results are presented in a list-style manner. Products that were selected by the user are placed in the user's shopping cart. The payment of products is similar to the Auction House; the payment information is entered by the user via an input mask. As soon as the products were paid, they are transferred from the cart to the user's inventory.

Trading

The current version of the prototype supports two different kinds of products: flights and hotels. A hotel product represents a reservation for a hotel room while a flight product represents a seat reservation for a certain flight. Furthermore, products can be distinguished by two additional attributes.

The first attribute defines how a product is sold. A product is either a fixed price product or an auction product. A fixed price product is sold for a fixed price in the Travel Agency while an auction product is sold via an English auction in the Auction House. An English auction is an open ascending price auction. The auction starts with an initial price after which bids are issued. The first bid must exceed the initial price and the subsequent bids must exceed the price of the previous bid. The bidding continues until no further bids are issued and the person who placed the last bid is announced the winner. The auction type of an English auction was chosen because it is perhaps the most prevalent type of auction (Krishna, 2010, p. 129) and it is perfectly suited for the visualization in a 3D Virtual World. Typically, these auctions are conducted in an auction house where all the bidders are co-located in the same room. This setting can directly be recreated in a 3D Virtual World and provides a familiar auction environment for the user. The second product attribute defines how products are added to the system. A product is either added manually to the system or via a third party product data provider. Products can be added manually with the Administration Tool - a wizard is used to define the attributes and content of the product. Alternatively, products are created automatically based on real world product information of third party tourism product providers. While this has not yet been implemented in the current prototype, it will be supported through the integration of the hybrid semantic search system (cf. Section 1.1). The automatic generation then works as follows. When the user searches for a certain kind of product, e.g. a hotel room in Vienna, the software agents in the Ameli system query several hotel search interfaces on the Internet. The search results are merged and presented to the user in the 3D Virtual World. If the user decides to buy one of the externally retrieved products, a new "virtual" product is created within the system. This virtual product contains the same information as the external one and can be sold to the user within the system.

The product purchase process is the same as in known interfaces where the search criteria are provided via input masks. Such a design was chosen as it is an effective means to quickly enter multiple data items and users are already familiar with these kind of interfaces. To search for a product, the user enters the Travel Agency in the 3D Virtual World and issues a search request. The request is then sent to the user's controlled agent which issues the request in the Ameli system. This triggers the autonomous agents to search for information in the internal database. All the results are merged and presented to the user in a coherent format. The user can browse the list and select certain offers that are placed in the user's shopping cart. In order to provide the user with familiar real world shopping metaphors, the products are to be paid at a counter before the user leaves the building. The user is not allowed to leave the building if unpaid products remain in the shopping cart. The payment process is conducted with a credit card. The user enters the credit card information and the products move from the shopping cart to the user's inventory. If the user decided to buy a product that was retrieved from an external data source, a new virtual product is created in the internal database. The creation process in the internal database is delayed until this moment in order to avoid a creation overhead and to only create products that are really needed internally.

The representation of products within the system closely resembles the way how tourism products are managed in the real world. We use the concept of room and flight contingents that can be purchased by so called providers. A provider is a company that buys room contingents from hotels or seat contingents from air line companies and sells them to customers. The provider pays a fixed amount for a certain contingent and defines the prices of individual rooms and seats. In our model, a room or seat can only be sold if it is contained in the contingent of a provider and if it has an assigned price. A product itself contains seat or room reservations identifying the seats and rooms that are sold in this product. In the case of a fixed price product, the product price is the sum of all rooms or seats contained in the reservation. In the case of an auction product, a start price has to be defined and the product will be sold for the end price that is reached in the auction. Only manually added products may be sold in an auction.

User Profiles

Profiles are one of the cornerstones of most successful and popular social networking sites like Facebook[2]. A profile is a concise representation of a user's personality and interests, allowing other users to easily get an impression of the person behind the nickname/avatar.

In Itchy Feet we also support profiles. They are filled out upon registration and can be modified later from within the 3D Virtual World. The profiles contain personal information like name, age and nationality and more touristic related information like traveler type, favorite countries and traveled countries. The controlled agent stores the profiles on the middleware layer and controls access to them. Hence, the controlled agent defines which other software agents/components are allowed to access what kind of information. A property that is especially important in the case of confidential information like credit card numbers.

[2] http://www.facebook.com/ (last accessed 02.05.2010)

Participation

In the following we aim to provide a general overview on the functionalities of the Itchy Feet platform by attending Elaine who visits the different places within the 3D Virtual World. Before she is able to visit the platform, Elaine must complete the registration process and is then able to use her personalized alter ego represented as a 3D character.

When Elaine walks around in the 3D Virtual World, her controlled agent performs the same movements in the Electronic Institution. We will illustrate how Elaine's agent moves around in the Electronic Institution and show which entities are entered and exited. Elaine will then post a question in the message forum and we will show how the message is sent to the *ForumAgent* in the Forum Electronic Institution. Furthermore, the realization of auctions in the 3D Virtual World is showcased. An example is provided in which Elaine participates in an auction together with another user and a software agent.

In detail, users participate in the Itchy Feet system via the 3D front end, i.e. the 3D Virtual World. Currently we support two different types of user roles which are customer and employee. A customer is the common type of user that participates in the system to gather information, socialize with other users and purchase products. An employee works for a certain provider and can offer professional help to customers seeking for certain information or products. An employee is much like a travel agent in a travel agency.

The Login Procedure

The first time a user connects to the 3D Virtual World, she is guided through a series of screens where a user name has to be chosen and personal information about this user is gathered. A customer account can be created by anyone, while an employee account must already exist in the system before an employee connects for the first time. Upon finishing the registration, a new controlled agent is instantiated and associated with the new user. The entered data is stored by the controlled agent on the middleware layer, which also controls access to this data. Further, this controlled agent is used to represent the user within the Ameli system.

When the user has completed the registration or logs into the system, she is spawned as a new avatar in the 3D Virtual World. At the same time the controlled agent enters the Ameli system and also moves into the Ether Electronic Institution. This process is illustrated in Figure 4.10. The Figure shows the 3D Virtual World in the upper right corner and a monitoring tool of the Ameli system in the lower left corner. The monitoring tool displays the current state of the Ameli system. In the left part all the agents

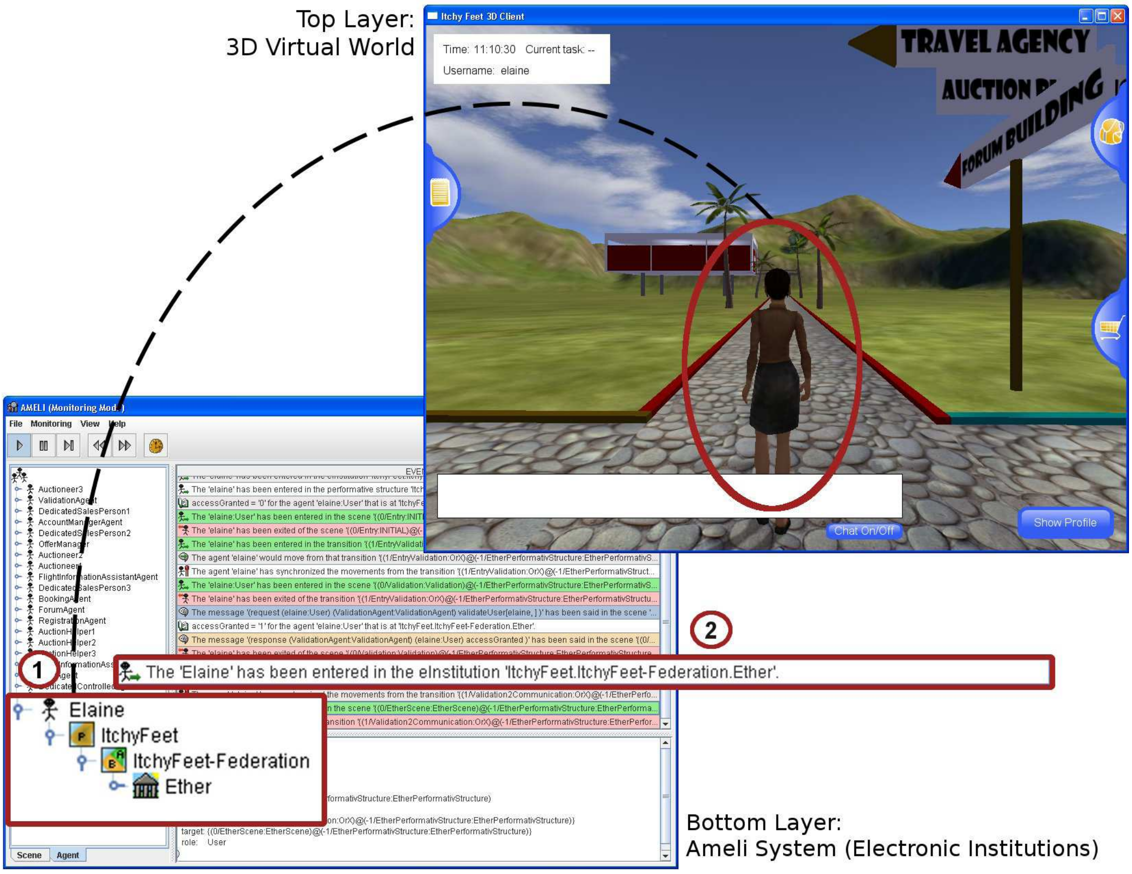

Figure 4.10: The user Elaine has entered the 3D Virtual World which triggered her controlled agent to enter the Ether Electronic Institution.

that are currently present in the system are shown. In Ameli, Electronic Institutions are organized according to a three layered structure. An Electronic Institution is executed within a Federation, which is executed within a Platform. In the monitoring tool we can see that Elaine's agent has entered the Platform "ItchyFeet", the Federation "ItchyFeet-Federation" and the Electronic Institution "Ether". All the messages that have occurred in Ameli are shown in a list in the right part. In the area below the list, more detailed information for selected messages is displayed.

As can be seen in Figure 4.10, Elaine was spawned in the 3D Virtual World as a new avatar. The monitoring tool shows that her controlled agent entered the system (1) and is now participating in the Ether Electronic Institution (1,2).

Moving around in the 3D Virtual World

The avatar movement is controlled by the keyboard and the looking direction is controlled via the mouse. In the 3D Virtual World the user is able to either perform actions that are

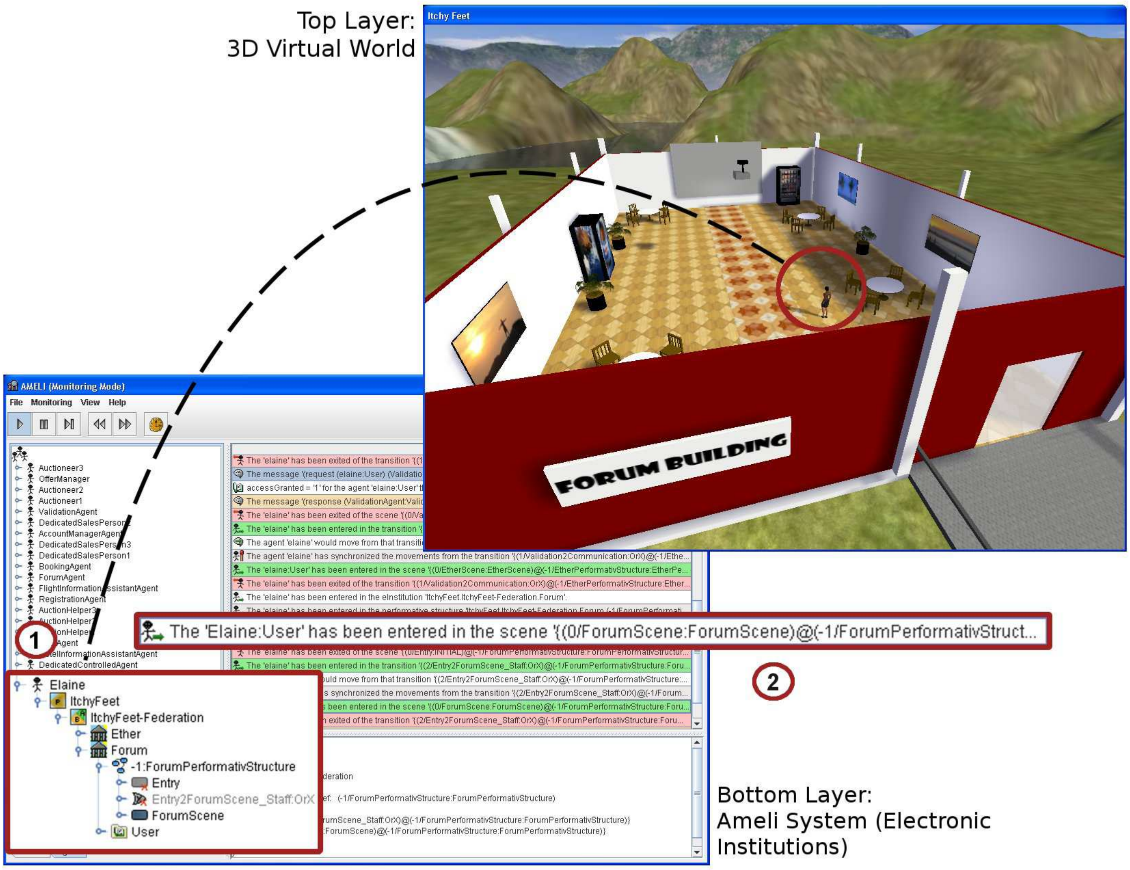

Figure 4.11: The user Elaine has moved into the Forum building which triggered her controlled agent to enter the Forum Electronic Institution.

permitted in the Ether Electronic Institution or she can walk around in the world and enter one of the three buildings.

The user can enter a building by pressing a certain key when standing in front of a door. A request is issued to the controlled agent which verifies that the user is allowed to enter the room behind the door. If the user is allowed to enter, the door will open and the user can enter the building. As soon as the building was entered by the user, the controlled agent tries to enter the Electronic Institution that is mapped onto this building. Depending on the user's movement within the building, the controlled agent "follows the movement" in the Electronic Institution and tries to enter scenes and transitions.

This process is exemplified in Figure 4.11. Elaine has just entered the Forum building in the 3D Virtual World and is now standing inside the building. In order to maintain the consistent relationship with the Ameli system, Elaine's controlled agent must enter the Forum Electronic Institution. This action has been executed successfully and Elaine's agent is now also present in the Forum Electronic Institution (1) where it is participating

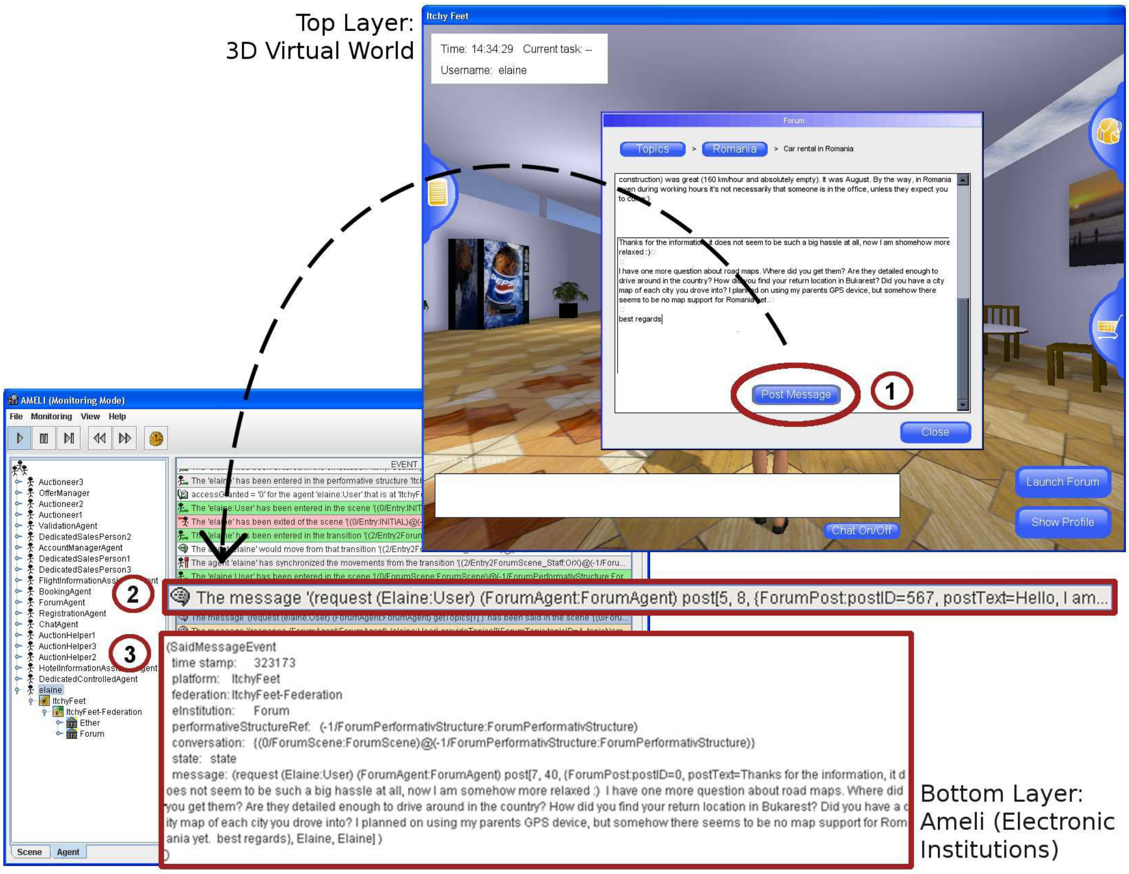

Figure 4.12: The user Elaine is posting a message in the Forum building, her controlled agent is uttering the message in the Forum Electronic Institution.

in the Forum Scene (2).

Entering a Building

Inside a building, the user is able to execute the business processes that are defined in the underlying Electronic Institution. In the case of the Forum building, the functionalities are defined in the Forum Electronic Institution. According to the Electronic Institution specification, a user is able to view threads and postings, can create new threads and is able to post messages.

These functions are realized in the 3D Virtual World via a 2D forum interface. Upon launching the interface, a request for the forum topics is sent to the user's controlled agent, which, in turn, sends a request to the *ForumAgent* for the currently available topics. The message is returned to the 3D Virtual World by the controlled agent and the topics are listed in the forum interface. The user is then able to browse the topics, to display the threads of a topic and to display the postings of a thread. The respective thread or post information is also retrieved via the user's controlled agent and the *ForumAgent*. The same applies to the creation of new threads and posts.

In Figure 4.12, Elaine has launched the forum interface and is currently viewing the topic "Romania" and the thread "Car rental in Romania". The posts of the thread are displayed in a scrollable list. A new post can be created via the text area at the bottom of the list. Elaine has just entered a new message and has pressed the button "Post Message" (1). A post creation request is sent to her controlled agent. The agent sends the message "post" to the *ForumAgent* in the Ameli system (2,3). The message is processed by the *ForumAgent* and a new post is created in the external Web forum.

Participation in Auctions

The auction scene is visualized as a separate room of the Auction House in the 3D Virtual World. The auction room as well as the auction interface are shown in Figure 4.13. The auction interface shows the item to be auctioned, the current status of the auction and contains an input box where the next bid is entered. The screenshot shows Elaine and three other actors which are participating in the auction. Two of them are autonomous software agents and on of them is another human user who is logged in the 3D Virtual World as well. The autonomous software agents are visualized by the 3D Virtual World. The roles of these agents determine how and where they are visualized. The *Auctioneer* agent, which is responsible for conducting the auction, is visualized on the stage behind the podium. The other autonomous agent is playing in the *User* role and is also interested in buying the product. This agent is visualized among the other users and is wearing the alien-like outfit. The different locations and outfits of each agent role help the user to quickly identify the duties of each avatar and make it easier to differentiate the individual avatars.

The upcoming auctions are displayed on an information panel in the information room of the Auction House. When a user decides to participate in an auction, she enters the auction room. As a consequence the user's controlled agent enters the auction scene in the Electronic Institution. The *Auctioneer* starts the auction at the given time following the auction protocol. When a bid is submitted by the user, a request is sent to the user's controlled agent, which sends out a bid message in the auction scene of the Auction House Electronic Institution. The actions of each user and agent are visualized in the 3D Virtual World by gestures and other visual cues. The bidding is illustrated by a hand raising gesture and by a message box with the bid amount that pops up over the avatar. If a user is announced the winner of the auction, the product is displayed in the shopping cart in the 3D Virtual World. The product is then to be paid in the clearing room where

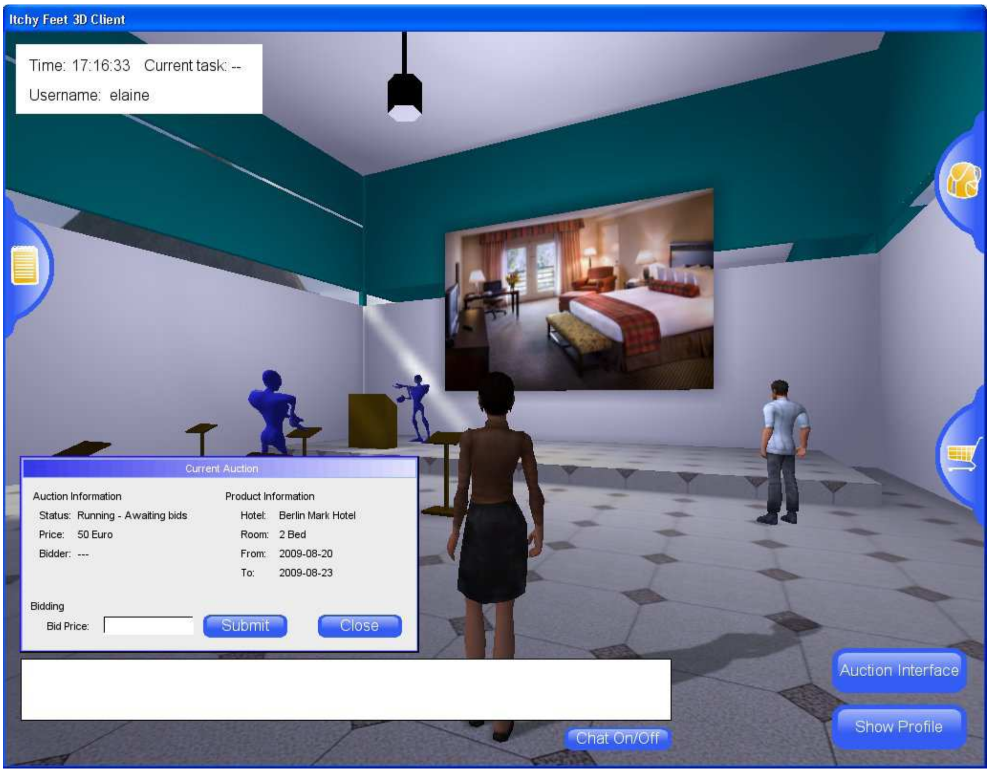

Figure 4.13: Elaine is participating in an auction.

the clearing scene is visualized.

4.5 Summary

In this Chapter the 3D e-Tourism environment Itchy Feet was presented, both from a user point of view as well as from a technological point of view. We saw what kind of functionalities are available to users in the 3D Virtual World, illustrated how the connection between the 3D Virtual World and the Multi-Agent System works and presented the technical framework that enables this connection. The motivation for building the environment was driven by several needs. They encompassed the provision of a familiar environment for end users that facilitates communication and provides the social warmth that is often missing in e-Commerce systems, the creation of an environment that enables us to study the application and utility of 3D Virtual Worlds in the tourism domain and the development of a framework that ensures trust through Electronic Institutions and further contributes to and extends the concept of Virtual Institutions within an application specific context.

CHAPTER 5

Itchy Feet Evaluation

Evaluations form a central role in our process model which was in introduced in Chapter 3. The principal evaluation design is typically independent from the 3D Virtual World technology and can be employed across different platforms. In Section 5.1 of this Chapter we first provide an overview on evaluation methods and user studies in 3D environments. Then the focus is laid on the evaluation of Itchy Feet and the third research goal of this thesis, evaluating the usability and acceptance of a 3D e-Tourism environment, is addressed. The employed evaluation design including a detailed description of the four subgoals of the evaluation is presented in Section 5.2. This includes the evaluation of the usability and system performance, studying the interaction design, getting insights on the employed e-Commerce facilities and evaluating different navigation metaphors. In Section 5.3 we present how the evaluations were executed and illustrate which kinds of data were gathered. The results are then presented in Section 5.4 and the research questions of the evaluation are answered.

5.1 Background

Evaluation Methodologies

In Section 2.4 we discussed the possibility to apply research results of the Virtual Reality domain to 3D Virtual Worlds. Especially in terms of evaluation methodologies there have been research efforts in the Virtual Reality domain which are also applicable to 3D Virtual Worlds as they do not place any assumptions on the used technology. Bowman et al. (2002) provide an overview on different methods for the usability evaluation of Virtual Reality applications. Methods are classified according to three different dimensions: involvement of representative users, context of the evaluation and types of results produced. The context distinguishes between generic evaluations and application specific evaluations, the user involvement classifies between methods that require users and those that do not require users and the results that are produced are either quantitative or qualitative. In our case where the overarching goal is to investigate the acceptance and usability of the Itchy Feet environment, we aim at an application specific evaluation with user involvement that produces qualitative results. The methods that are suggested for this type of evaluation are: (informal or formal) formative evaluations, post-hoc questionnaires and interviews/demos. As an example for an application specific evaluation approach they present a methodology that was postulated by Gabbard et al. (1999) and refined by Hix and Gabbard (2002). This methodology is defined on a general level without making assumptions on certain technologies or characteristics that are only relevant in the context of Virtual Reality applications. We therefore based our evaluation on this approach and conducted similar activities during the design and evaluation of Itchy Feet. The key elements of this approach are user task analysis, heuristic evaluations, formative evaluations and summative evaluations which are performed in a sequential progression. The utility of this approach was demonstrated through several case studies (Hix and Gabbard, 2002; Hix et al., 1999). The authors showed that expert heuristic evaluations and formative evaluations work well when developing Virtual Reality applications and greatly contribute to the usability of the environment. They state that Virtual Reality applications are too often created without the user in mind and call for the integration of usability engineering methods within the development cycle of Virtual Reality applications. In the same manner we employed usability engineering methods during the development of Itchy Feet and designed the environment form a user's point of view. This methodology will be presented and discussed in more detail in Section 5.2.

A similar approach for developing 3D environments is taken by Dang et al. (2008). They propose a framework for the design and evaluation of Collaborative Virtual Environments. In an iterative process, the environment is first designed, then developed and then evaluated. Evaluations take the form of expert inspection-based evaluations and observational evaluations with users. In inspection-based evaluations a group of evaluators inspects the interface according to a set of guidelines related to collaborative work. In observational evaluations, the behavior of participants is observed while they perform representative tasks in the environment. The feedback of the participants is collected and analyzed to identify problems with the design. A Collaborative Virtual Environment was developed to verify the suitability of this process and was evaluated in an informal user study. They conclude that the iterative application of inspection based and observational evaluations were effective means to identify usability problems and to improve the environment. The same types of evaluations can be found in the work of Tromp et al. (2003). They present an evaluation strategy that was employed during the development of a Collaborative Virtual Environment. Evaluations were conducted in four threads of work: usability inspection, observational evaluations, consumer evaluation and the formulation of guidelines. During the usability inspection they performed cognitive walkthroughs and heuristic evaluations to identify problems in the design. The cognitive walkthrough is based on task sequences which define how the user will later actually use the system. The usability inspector performs the steps that are defined in the task sequences on the preliminary design and identifies potential problems. In the heuristic evaluation, the usability inspector compares the design with established design heuristics and identifies discrepancies between the design and the heuristics. In observational evaluations, participants are observed under controlled experimental settings. A method was created and employed to study the interactions between users and to capture data on the interactions in a quantitative way. The consumer evaluations were used to capture the needs and attitudes towards the application by means of surveys and interviews. They were performed at the beginning and at the end of the project. At the end of the project, the cumulated experience led to the formulation of usability guidelines to provide a systematic method for developers of CVEs.

The application of heuristic evaluation to Virtual Reality applications was further studied by Sutcliffe and Gault (2004). Based on previous general usability heuristics and experiences from the Virtual Reality domain, they created twelve heuristics to be used in expert evaluations of Virtual Environments. These heuristics include, for example, navigation and orientation support, natural engagement and faithful viewpoints. They present a method that outlines how the heuristics are used during an evaluation and report on the successful application of these heuristics in three case studies. We utilized these heuristics in our expert evaluations and designed our environment to comply with these suggestions. Livatino and Koeffel (2008) did an analysis of user studies in Virtual Environments and compiled an evaluation guideline. The guideline includes steps such as participant selection, formulating the research question and constructing a test plan. They conducted two case studies in telerobotics in which they verified the usefulness of the guideline. This guideline also inspired our evaluation procedure.

User Studies in 3D Environments

The methodology of Gabbard et al. (1999) was applied by different researchers to perform empirical user studies. One example is the work of Drettakis et al. (2007) in which they developed a tool for redesigning the main open spaces in Nice for a tramway project. They started with a detailed user requirements process and involved designers and users from the beginning. The system was build in several iterations and evaluated in an in-depth qualitative evaluation. Furthermore, they mention that many Virtual Reality applications are prototypes with a specific context and that few real world applications exist. It is therefore necessary to apply and evaluate 3D environments in a real world context; a topic that is addressed in our evaluation. Another example for using the methodology of Gabbard et al. (1999) is SMILE (Science and Math in an Immersive Learning Environment). SMILE is a learning environment for deaf and hearing children created by Adamo-Villani and Wright (2007). The environment is composed of several buildings such as a bakery and a candy store in which children learn about math and science concepts through hands-on activities. For example, the assembling of a clock requires children to apply math techniques such as counting and adding. Help is provided through avatars which communicate with the children in written, spoken and sign language. The system was developed and refined in several iterations according to expert panel based evaluations. In these evaluations experts on Virtual Environments, 3D modeling and sign language evaluated the system with focus on their area of expertise. The usability and fun of the environment was assessed in a formative evaluation with school children aged from five to ten years. In order to motivate school children during the evaluation, they designed the environment as a fantasy world and created game like scenarios such as a cake baking activity. In a similar fashion we designed our evaluation along a scenario in order to motivate the test users and to engage them in the evaluation. Another example for using scenarios in an evaluation of a Virtual Reality application is the work of Sousa Santos et al. (2009). They compared a non-immersive traditional desktop setup with a fully immersive Head Mounted Display (HMD) in terms of user performance during navigation tasks. In order to make the evaluation more natural, users were not directly presented with single navigation tasks, but the evaluation was embedded in a game scenario. A maze was created in which users had to find and collect several items by navigating around in the environment. While playing the game, the users implicitly performed different types of navigation tasks that were recorded and analyzed by the researchers. A work that is embedded in an application context is the Multiscale Virtual Environment which was created by Kopper et al. (2006). In this environment users are able to zoom in on a human body and can learn about the human anatomy. They evaluated their work in a usability study where they compared different scaling methods with each other.

While the previous studies have all taken place in Virtual Reality environments, empirical user evaluations have been conducted in 3D Virtual Worlds as well. The collaboration between users in 3D Virtual Worlds was studied by Tromp (2001). In collaboration with other researchers, she implemented a version of the board game Cluedo in a 3D Virtual World. In this game multiple players have to investigate a murder case and find out who killed the victim. The game is solved collaboratively and their system was evaluated in a usability study were multiple people at different remote locations played the game together. The game scenario was used to repeatedly engage users in evaluations that lasted one hour and enabled the researchers to study the collaboration between the users. Singer et al. (2008) also employed scenarios to evaluate the potential of a 3D Virtual World. Their work is placed in the domain of military simulations where they created a 3D Virtual World for asymmetric warfare training. Asymmetric warfare in this case refers to the combat against terrorists where soldiers have to fight in unknown territories and the tactics and strategies of the opponent are unpredictable. An urban territory was created which resembled Baghdad, the capital of Iraq. A checkpoint operation was selected as a suitable scenario to evaluate and demonstrate the potential of the environment. In a checkpoint operation soldiers have to set up and maintain a checkpoint. Two formative evaluations were conducted with this scenario to identify usability problems and to improve the environment. The following works also report on empirical user evaluations in 3D Virtual Worlds, but they were not conducted in a specific application context or employed an evaluation scenario. Nevertheless, the principle structure of these evaluations is similar to our work. Users had to perform tasks in a 3D Virtual World during which data was collected and the performance of users was observed. The data was then used to derive results, to get new insights and to answer the research questions. Chittaro and Burigat (2004) developed a navigation aid for 3D Virtual Worlds and evaluated its usefulness in a usability study in two different worlds. In another work, Tan et al. (2001) created a navigation taxonomy for 3D Virtual Worlds and they compared different navigation and object manipulation methods. Users had to perform tasks such as navigating to a certain location or moving objects around in the world. Modjeska and Waterworth (2000) also studied navigation in 3D Virtual Worlds, but in the context of information visualization and information retrieval. In a usability study people had to search for information in a 3D Virtual World under different settings.

5.2 The Evaluation Design

The overarching goal of the evaluation was to investigate the acceptance and usability of the Itchy Feet environment and to get insights on the applicability of 3D Virtual Worlds in the tourism domain. It was therefore important to embed the evaluation in a real world application context and to create a use case that is based on activities that people usually perform when planning their trips. A scenario was developed to engage users in the evaluation and to embed the functionalities of Itchy Feet in a real world use case. The resulting tasks, such as performing an information search or participating in an auction, exhibited rather different characteristics and were not well suited for a quantitative comparison. Additionally, as this was a scoping study, we had a strong interest in the opinion of the users and a qualitative approach was identified to be most suitable. Test users were observed during the evaluation and qualitative data was gathered in two interviews. The first interview was conducted before the evaluation and addressed questions about the users background, their experiences with 3D Virtual Worlds and their travel behavior. The second interview was conducted after the evaluation and users reported their experiences and opinions about Itchy Feet. The interview data, the observational data and task performance results were used to investigate the four following goals.

Goal 1: Usability and System Performance

The objective of the first goal was to investigate the usability of the environment and to find out if users are able to complete the scenario, if they can orient themselves and navigate around in the world and what kind of difficulties arise during task completion. Additionally, we planned to assess the system performance, since all user actions are verified in the Multi-Agent System and all messages are sent via three layers. We wanted to find out how well this design had been implemented and if a responsive 3D Virtual World on top of a Multi-Agent System had been created.

To find answers to these questions, the system performance as well as the behavior of users were observed during the evaluations, users had to rate the difficulty of the tasks in the post evaluation interview and were asked about the usability and the problems they had experienced.

Goal 2: Interaction Design

A central element of the Itchy Feet project is the provision of an environment that helps to create and foster a tourism community. As part of a tourism community, communication and knowledge sharing facilities are necessary that enable users to interact with each other in different ways. They are provided in Itchy Feet by the forum, by the public chat and by the private chat. The forum acts as an information source, the public chat fosters communication between users and in the private chat professional travel agents are consulted. As part of the evaluation all these communication facilities had to be used and we were especially interested how users are acting when they talk to other users and travel agents. Additionally, we wanted to find out what types of information sources users consult when they usually plan their trips and how important they rate the personal interaction with travel agents, friends and other tourists in the planning stage.

In terms of interaction with the environment, a new concept whose usefulness we wanted to evaluate was the functional separation by the physical area in the 3D Virtual World. As outlined in Section 4.1, this separation builds on metaphors that people are used to from the real world and should contribute to the usability of the environment by reducing the complexity of the user interface. We wanted to determine if users are able to relate the accessible functions to the physical area by themselves, if they can handle the concept and what they are thinking about it. In order to investigate the application of this metaphor to a 3D Virtual World, we observed the users reactions during the evaluations and discussed the concept in-depth in the post evaluation interviews.

Goal 3: e-Commerce Facilities

Tourism products are predominantly traded at fixed prices on the Internet, while auctions are a largely unexplored type of distribution channel. In contrast, agent-based systems often rely on auction mechanisms to enable the trade of products between autonomous agents and human users. The agent based system architecture of Itchy Feet enabled us to also integrate auctions in the 3D Virtual World and we were able to explore this distribution channel in the tourism domain. The goal was to find out how well the adoption of an English auction works in a 3D Virtual World, if users are able to follow the auction protocol and what the users think about the possibility to buy tourism products in auctions.

The next point of interest was assessing the perception of 3D products. The goal was to find out how important a detailed presentation of tourism products is, what the test users think about the possibility to experience tourism products in a 3D environment and if a certain trend in their opinions can be observed. At the time of the evaluation, the integration of 3D products in Itchy Feet was not yet mature enough to be included as part of a task in the test sessions. In a first effort to identify the users opinions and ideas towards this type of product presentation, their attitudes were recorded in the post evaluation interview.

Goal 4: Evaluating Input Control Modes

The final focus of the evaluation was the comparison of different input control modes. The goal was to find out if the type of input control effects the performance of the user and if people have more difficulties with one mode than with another mode.

We compared four input modes that are differentiated by two characteristics. The first distinction is keyboard control mode vs. mouse control mode. In keyboard control mode, the control of the avatar is solely based on the “WASD” keys. The “W” key is used for moving forward and the “S” key is used for moving backward. The “A” key is used for turning to the left and the “D” key is used for turning to the right. It is not possible to look up or down in this mode. The mouse is used to control the mouse cursor which is constantly available in this mode and is used to perform actions on the user interface. In mouse control mode, the mouse is used to control the view (i.e. the user can look around with the mouse) and the “WASD” keys are used for walking. Again, the “W” key is used for walking forward and the “S” key is used for walking backward. In difference to the keyboard mode, the “A” key is used for walking sideways to the left and the “D” key is used for walking sideways to the right. Another difference is that the mouse cursor is not displayed when the user walks around. In order to be able to interact with the user interface, the mouse cursor has to be switched on. This is achieved by pressing the tabulator key. When this key is pressed, the mouse cursor appears on the screen and from this point on the mouse pointer is controlled via the mouse. As long as the mouse cursor is turned on, the user cannot walk around. When the user wants to continue walking, the mouse cursor has to be switched off by pressing the tabulator key again.

The second distinction is third person view vs. first person view. In third person view the user is able to see her avatar. The avatar is seen from the back and is standing in the middle of the screen. When the user walks around, the camera follows the avatar and the user sees how the avatar moves forward, backward and sideways. In the first person view the avatar is not shown. The monitor directly shows the 3D Virtual World and when the user walks around, the view changes, e.g. when moving towards a house, the house appears to be getting nearer and nearer.

The combination of these different settings led to four different modes that we compared with each other. The test population was divided into four groups and each group had to conduct the evaluation in a different input mode. The four modes are as follows.

- **KF** mode - keyboard mode combined with first person view
- **KT** mode - keyboard mode combined with third person view
- **MF** mode - mouse mode combined with first person view

- **MT** mode - mouse mode combined with third person view

Evaluation Procedure and Methods

The design and evaluation of Itchy Feet was based on the methodology proposed by Gabbard et al. (1999) and Hix and Gabbard (2002). This methodology consists of four consecutive steps. They are *user task analysis*, *expert guidelines-based evaluation*, *formative user-centered evaluation* and *summative comparative evaluation*. It is interesting to observe that while they present their methodology as a sequential execution of the four activities, they also argue that the methodology is highly iterative. The iterations take place within the four steps themselves which might be carried out in an iterative fashion. Thus, the sequential ordering defines how the different types of evaluations are conducted over the timeline of the development, while the iterative nature describes how the evaluations themselves are conducted. In the user task analysis step, the users needs are analyzed and the necessary tasks for the system are identified. In the case of Itchy Feet we iteratively developed a set of use cases which where then used as input for the software requirements document. This document formed the basis of the functionality that was implemented in Itchy Feet. The task descriptions together with usability guidelines and heuristics (Bowman et al., 2004; Stanney et al., 2003; Gabbard and Hix, 1997) then influenced the design of the user interface. The user interface was revised and improved in the second phase. We conducted expert walkthroughs in which experts verified the proper realization of the requirements according to heuristics and the compliance with usability standards. The interface was then evaluated in the third phase in a formative user-centered evaluation. The results of this formative evaluation are the focus of this Chapter. In the last step of the methodology the system is summatively compared with other applications and the user performance is compared between the different applications. The summative evaluation of Itchy Feet will be subject to future work and has not been carried out so far.

For the evaluation we adopted the creation of task based scenarios from the methodology. A scenario with 18 tasks was created that guided the test user to all functions available in Itchy Feet. The evaluation itself was based on a standard usability evaluation (Nielsen, 1993) following the guidelines given by Livatino and Koeffel (2008). This included suggestions on the evaluation setup, number of participants and conduction of pilot tests. The methods of usability evaluations, such as user observations and interviews, have been successfully applied in the Virtual Reality domain (Stanney and Zyda, 2002; Hix and Gabbard, 2002). We leveraged these techniques for the evaluation of Itchy Feet as well. The users completed the tasks one after another and their actions and behavior were recorded on video. The evaluator was sitting next to the test person, observed her and took notes. The reactions of the user as well as the activity on the screen were recorded on video for later analysis.

Scenario Based Evaluation

The scenario was designed along a real world e-Tourism business case ranging from the initial travel planning to the product selection to the product purchase. Additionally, we aimed to sustain the playful character of 3D Virtual Worlds by creating a scenario that is a fun experience and motivates the test users. The task descriptions were integrated into the 3D Virtual World and users could track the current task progress similar to the progress of a mission in a computer game.

In order to create this playful character, the test person slips into the role of another character and first has to find out some information about herself and about her travel plans. Note that we have created a version for male and female test persons, but are using the female version in the following for ease of reading. In the case of the female scenario the fictitious character is named “Susan Miller”. The test person learns that she made some travel arrangements with another user named “Elaine” and that she has to book the journey with Elaine’s credit card. Elaine is present in the 3D Virtual World and played by another project member. The test person has to meet Elaine and has to collect the credit card information at different places in the world. Then she has to find out which hotels are recommended by talking to an employee in the Travel Agency. The employee is played by the project member as well. The test person then has to book one hotel room at a fixed price in the Travel Agency and the other hotel room has to be purchased in an auction. In the auction she has to compete with autonomous agents and place several bids to be the winner of the auction. The scenario is completed as soon as the user has won the auction and has paid the hotel room in the Auction House. A detailed overview of all the tasks can be found in Appendix C.

Task Types

The scenario contains three different types of tasks: *Movement Tasks (MT)*, *Action Tasks (AT)* and *Information Tasks (IT)*. In a movement task, the user has to walk to a certain location. The path to the target location is not defined and different users might take different paths. The task is completed when the user enters the area around this location. Action tasks involve interactions with the user interface. This mostly involves the triggering of an action by pressing a button or completing a sequence of actions on the user interface. Such a task is completed as soon as the user presses the correct button or performs the correct action. The last type of task are information tasks. In an information task the user has to find out a certain piece of information that is available in the environment. The information then has to be entered in input fields and the task is completed if all the provided information is correct.

Task Interface

The *Task Interface* enables the user to execute all tasks autonomously. It contains a description of the task, visualizes the task progress and automatically detects the successful completion of a task. The user is able to open the task interface at any point during the evaluation in order to review the current task description. When a user finishes the current task, the task interface automatically pops up, acknowledges the successful completion of the task and the user can move on to the next task. The task interface is shown in Figure 5.1. It contains a progress bar to inform the user about the progress of the evaluation, a title and a description of the current task and buttons to start a task and to close the interface. The user starts a task by clicking on the "Start Task" button. When this button is pressed, the timer for this task is started, the task interface is closed and the user can start to work on the task. When the task interface is opened again, the "Start Task" button has changed into a "Close" button. The only action the user can perform in the task interface during a task is to review the description and to close the window.

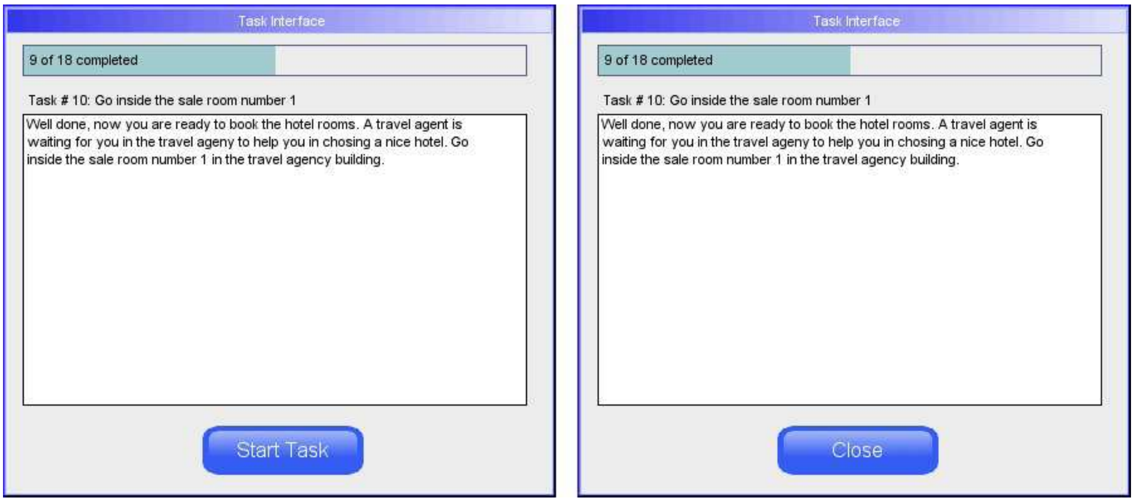

Figure 5.1: The task interface (before and after the task was started).

The type of the task determines how a task is completed. In the case of a movement task, the task is completed as soon as the user enters the area around the location that is specified in the task. In the case of an action task, the task is completed upon a certain operation on the user interface (e.g. when a button was pressed or a wizard was completed). The task interface pops up as soon as a task was completed and then the next task can be started. In the case of an information task, the task interface looks differently. This is illustrated in Figure 5.2. The information that has to be found out in the task has to be entered via input boxes. Upon an information task, the task interface changes dynamically and questions as well as input boxes for the answers are added. In contrast to the other tasks, an information task is not completed automatically. The user has to click on the “Check Answers” button to verify the correctness of the entered answers. The task is completed as soon as all the entered answers are correct. The user can then proceed to the next task. If an entered answer is incorrect, an error message is displayed and the user has to correct this answer to be able to complete the task.

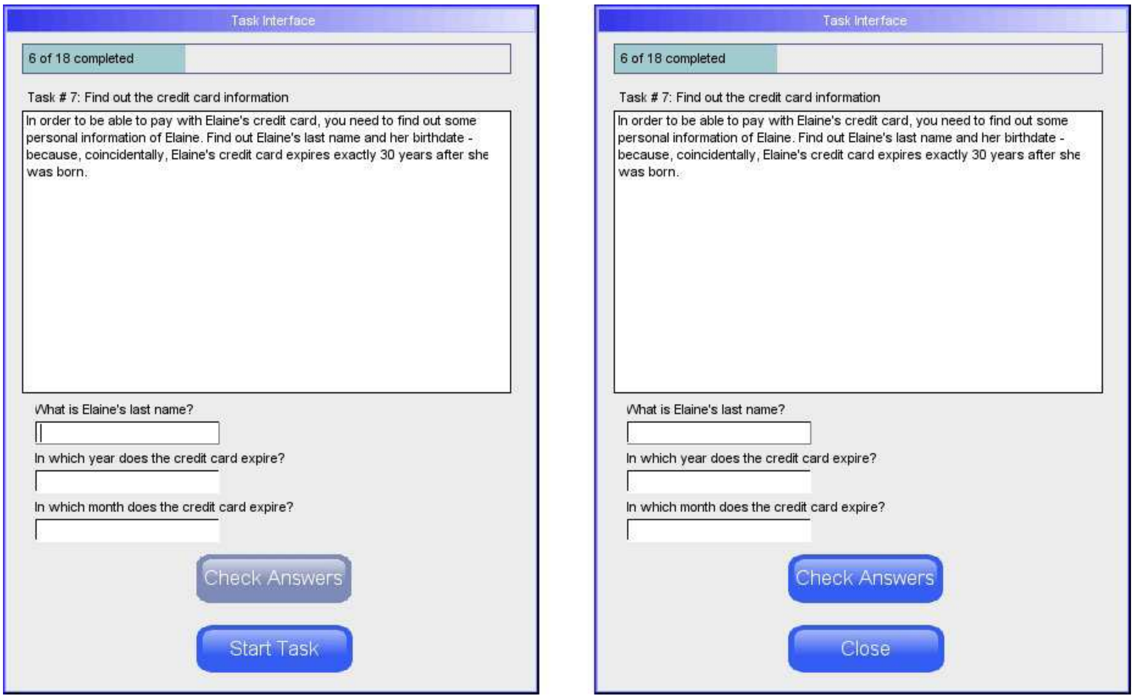

Figure 5.2: The task interface showing an information task (before and after it was started).

The Experimentation Area

In the evaluation people do not directly start with the scenario, but first have to complete four tasks in an experimentation area. There they can get familiar with the environment, learn how the task interface works and how it is used. After completing the four tasks, people are allowed to spend as much time in the experimentation area as they wish. The evaluation is started by the test person herself when she feels ready.

The experimentation area consists of a bridge over which people can walk and a small building with one room that can be entered. When entering the experimentation area, the task interface is automatically opened and the control system as well as the functionality of the task interface are explained. The first task is a movement task in which the user has to walk onto the bridge. In the second task, the user has to perform an operation on the user interface and open the notepad. In the third task the user learns how a door is opened (by pressing the "E" key) and is required to enter the small building. The last task is an information task in which the user has to find out who has written his name on the wall of the building. In order to complete this task, the user has to leave the building and walk around it. On the exterior wall she then finds a writing on the wall saying "Helmut". The task is completed by entering the information in the task interface. As soon as the task is completed, a new button "Begin Evaluation" appears on the user interface. The test person is then able to start the evaluation by clicking on this button whenever she feels ready. A detailed overview of these tasks is included in Appendix D.

The Evaluation Set Up

The complexity of the tested system required a total of twelve applications running on three different computers to conduct one evaluation. This setup is shown in Figure 5.3. The evaluator and the test person are sitting in Room A, while another project member is sitting in Room B playing Elaine and the employee. The evaluator is able to control the evaluation from his computer - the framework as well as some auxiliary software is running on this computer. The framework is made up of the following components which also have to be started in this order from top to bottom:

- The database where the data is stored (user profiles, hotels, reservations, ...)
- The Multi-Agent System
- The Connection Server connecting the agent system with the 3D Server
- The 3D server executing the 3D Virtual World

The evaluator can use the framework manager to start and stop each of these components and to verify the proper execution of every component. A webcam is connected to this computer which is recording the test user (video and audio channels). A Skype[1] client is used to communicate with the other project member in Room B via a text chat. This communication channel is used to communicate problems and to inform the project

[1] http://www.skype.com (last accessed 14.05.2010)

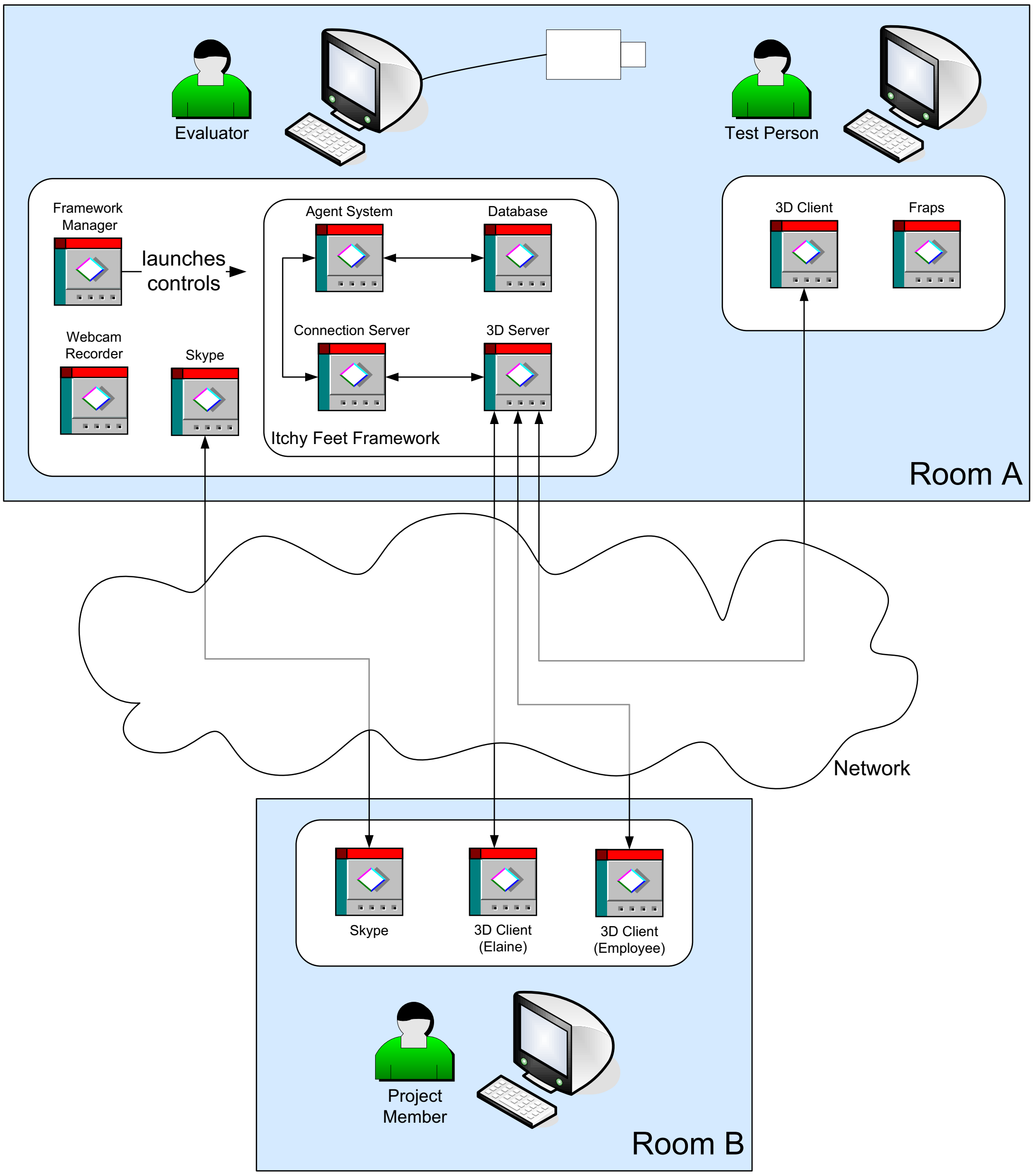

Figure 5.3: The evaluation setup.

member of the progress of the test user, such that he is ready to engage in the conversations.

The load on the other two computers is kept as minimal as possible due to the high resource needs of the 3D clients. The computer of the test user is running two applications: the 3D client with which the evaluation is performed and Fraps[2], a software for recording the user interface. On the computer in Room B, the second project member

[2]http://www.fraps.com/ (last accessed 14.05.2010)

executes two 3D clients and one Skype client. One 3D client is used to control Elaine in the 3D world, while the other 3D client is used to play the employee in the travel agency.

Pilot Tests

The execution of pilot tests before a usability evaluation is generally encouraged in order to identify problems and errors in the evaluation design (Nielsen, 1993). We conducted two pilot tests with male co-workers. The first one was conducted three weeks before the evaluation period and the second one was performed two weeks before the evaluation period. This provided us with enough time to change identified problems and some changes could already be incorporated before the second pilot test took place. The majority of these problems were comprehension problems of task descriptions. The test persons had problems with understanding some of the tasks. This was fixed by adapting the task descriptions and making them more clear.

Acquiring Test Persons

In consideration of our resources and general project conditions we chose to recruit test persons by posting calls on web forums, mailing lists and by sending out e-Mails. We did not place any requirements on the selection as this was a first scoping study and the environment was not designed for a specific target group. We expected to get enough responses by sending out one call, but soon learned that this was not the case. It proofed difficult to find enough people that were willing to come to our institution and participate for one hour in the evaluation. Our experiences and lessons learned are presented in the following.

In a first iteration we did sent out a call asking for interested people who are available for one hour to evaluate the system. The results were disappointing as we did only receive one reply within a week. We came to the conclusion that we would have to offer an incentive in order to motivate people to participate. In a second iteration we started to offer a 10 Euro Amazon gift certificate. Now people became interested and we did get a lot more responses (about 10 to 20).

However, we soon discovered another problem. We had distributed the slots for the evaluation equally from 9 AM to 5 PM within one week. But, people were only interested in the later spots which filled up quickly and the slots during the day remained empty. People seemed to prefer the later spots and if their preferred spot was not available they did not register in the time table. As a result, not every person who had responded to the call did register for an evaluation and we were not able to reach the anticipated number of participants. To counteract this problem we did open up new slots for the next two weeks with more appropriate times, i.e. more slots in the evening. We then informed the respondents that had not registered yet and did sent out a third call as well. In the end, after this third call, a total of 20 people did eventually register and also showed up for the evaluation.

The Evaluation Sessions

The evaluation sessions were conducted at the office of Matrixware Information Services GmbH[3]. We did have a separate room to keep the distraction during the evaluation as low as possible. An evaluation session was planned to last one hour and we scheduled a buffer of half an hour between two evaluation sessions. An evaluation session itself had seven different phases.

Pre-Phase

Before the test person arrived it was necessary to start up the system and to prepare all documents. The framework was started on the evaluator's computer according to the sequence as outlined previously (i.e. database, Connection Server, Multi-Agent System, 3D server). The second project member then started two 3D clients and connected to the 3D server. He then positioned Elaine's avatar behind the auction house and walked into the travel agency with the employee's avatar.

Then the auxiliary software was started. The Skype connection was verified, the program for recording the webcam was started and the audio software for recording the interviews was started as well. The correct function of the webcam and the microphone were then verified. Finally, the 3D client was started on the test person's computer and the monitor was switched off in order to not distract the test person in the beginning. Then we waited for the test person to arrive.

Welcome phase

In this phase the test person was welcomed and we offered them a drink. After the person had made herself comfortable in front of the evaluation computer, we shortly explained the content of the project, the project setting and the goals of the evaluation. It was explained what kind of data is collected and how it will be used. Then the test persons had to sign an informed consent form in which they agreed to the terms and conditions of the evaluation.

[3]http://www.matrixware.com/ (last accessed 14.05.2010)

Pre-Interview

In the pre-interview we first collected some demographic and personal data and then talked about the user's computer usage, her knowledge of 3D Virtual Worlds and her travel behavior. These interviews lasted about five minutes.

Evaluation

Then the evaluation was started. The monitor of the test person was switched on, the evaluator verified the correct settings of the input control mode and launched the evaluation. The test persons took over control of the avatar which was already standing in the 3D Virtual World. It was then explained that the users just have to follow the instructions on the screen and that they can ask questions at any time if they experience comprehension difficulties. The evaluator then became an observer and the test persons first finished the experimentation area and then completed the scenario. An evaluation took between fifteen and thirty minutes.

Post-Interview

After the successful completion of the evaluation, the post interview was conducted. It was structured into four blocks. In the first block the test users were asked about their opinions on the Itchy Feet system, the problems and critique were discussed. Then they had to rate the difficulty of the tasks on a 5 point rating scale and after that, in the third block, the input controls were discussed. Again there was a 5 point rating scale on which they had to rate the difficulty of the input control under certain aspects. In the last block, the hypothetical functionality of 3D products was discussed and people were asked about their attitudes towards the potential usage of the system. These interviews lasted between ten and thirty minutes.

Farewell

In the farewell phase we thanked the test persons for their participation and handed over the Amazon gift certificate. They had to sign a second document stating that they had received the certificate. We then walked the test person out.

Post-processing phase

In the post processing phase the recorded data was organized and stored in one place. The interviews and the recorded video were saved and copied into a new folder together with the log files.

5.3 The Evaluations

The evaluation period did last three weeks in June 2009 during which 20 people successfully participated in an one hour on site evaluation. In general, the evaluations went smoothly. People appeared punctually and we were only let down once or twice. The time buffer of half an hour between two sessions also turned out to be sufficient and it was a good decision to choose such a big buffer.

In terms of the framework we did experience some problems. Due to the prototypical nature of the system, the system crashed in five evaluation sessions. We then had to interrupt the evaluation and start the framework again. However, as we had included the possibility of a system failure in the planning of the evaluations, we could easily deal with this problem. All framework components could be started by the evaluator again. The communication channel to the other project member could be used to inform him of the problem and to request him to re-login once the system had restarted. In order to allow the test persons to continue with the same task, we had implemented a functionality to jump to a certain task. Therefore, as soon as the client had been restarted on the test person's computer, it was possible to jump to the task which the user had been working on at the time when the system had crashed. It was possible for the test user to just continue the evaluation without completing the already finished tasks again.

Data Processing and Analysis

The raw data that was gathered in each session had to be processed in different ways in order to serve as a basis for the analysis.

Interviews

The interviews were the major source for collecting qualitative data and for finding out the people's opinion on the environment and its functions. As outlined in Section 5.2, we had conducted two interviews: a short pre-interview before the evaluation and a longer interview after the evaluation. Both interviews had been saved in one audio file via a microphone that was connected to the computer of the evaluator. Due to hardware problems in the input channel some interviews had poor audio quality. Therefore, they were harder to transcribe and included more parts that were incomprehensible than those interviews with a better audio quality. The total length of all interviews was 740 minutes and 10 seconds with the shortest interview lasting 14 minutes and 50 seconds and the longest interview lasting 33 minutes. Every interview was then transcribed with f4audio[4] into a Word file. The transcription was a long and cumbersome process and eventually resulted in 198 pages of transliterated interviews. On average they were 10 pages long with the longest interview resulting in 15 pages and the shortest having 8 pages.

Case Based Summaries

The analysis of the interviews was based on procedures that were presented by Kuckartz et al. (2008). In a first step we created a case based summary for each interview. A case based summary is a bullet list of features that describes the person. The transcribed interviews were printed and we did work through each interview, marked important passages, wrote down notes and out of this data created a case based summary. These summaries helped us to get to know the test persons and to understand their motives better. After this analysis we were also able to create an initial coding system that was used in the next step in which the interviews were coded.

The Coding

The coding of interviews in qualitative evaluation is the process of marking text segments of the interview with a certain code. A code is a descriptive word or short phrase describing a certain property that is of interest for the analysis. Examples of generic codes that we used are “Critique”, “3D Virtual World” or “Travel Behavior”. The coded interviews then enable the researcher to detect clusters of codes and to interpret the data in order to find out the motives and the reasons for a decision of the test persons. An illustration of the code system that emerged during the analysis can be found in Appendix E.

The code system can either be based on a theoretical framework or evolves out of the data in an iterative fashion. In our case, where no related theoretical frameworks exists, we chose the latter approach and the coding system evolved during the analysis. The coding itself was then performed with MAXQDA[5], an application that has been developed for this exact purpose. In the coding process we first started with a set of general codes that were then refined in subsequent iterations. For example, one general code was “Positive Critique”. After the first iteration we had labeled some 90 passages with this code. In the next step we had a closer look at these passages and created new sub-codes. This resulted in new, more specific codes, like “Interaction”, “User Interface” or “3D

[4] f4audio is an application especially tailored at the transcription of audio interviews. It includes functions to start and stop the replay with the function keys as well as jumping some seconds forward and backward. It’s a free software and can be downloaded from http://www.audiotranskription.de/ (last accessed 02.05.2010)

[5] http://www.maxqda.de/ (last accessed 02.05.2010)

World". In further iterations these codes were refined, passages were re-coded and, if necessary, even further sub-codes were introduced. This process was based on the stages of analytic coding as described by Lofland and Lofland (1995, p. 192). They separate the coding into two phases: "the initial coding" and the "focused coding". In the first phase the initial codings are created out of the "commitments, interests, expertise, personal history, knowledge of and skill with the topics". In the second phase this base corpus is used and further refined in an iterative fashion, where general codes are split into more granular codes, new codes are introduced and codes are merged together. The final result was a coding tree of all the interviews which could be analyzed with different methods that are provided by MAXQDA and which were used to derive the interpretations that are presented in Section 5.4.

Videos

In each evaluation session we had recorded two separate videos. The first video showed the test user sitting in front of the computer and included an audio channel. The second video showed the user interface and the audio was not recorded. These separate videos were not very useful by themselves as it was not possible to relate the reactions of the user to the actions on the user interface. In order to unleash their full potential, we created split screen videos. We arranged the two video sources horizontally showing the user on the left side and the user interface on the right side. This approach enabled us to directly observe how a user reacts to the events on the user interface. In addition it was possible to replay each evaluation session and to observe it as if being present during the evaluation. A freeze frame of such a video can be seen in Figure 5.4.

During the analysis the videos where used as an additional source for tracing down and verifying usability problems, to clarify ambiguous or unclear statements from the interviews and as a means to replay every evaluation session at any time.

Log Data

The quantitative data basis of our analysis was formed by different types of logs that were recorded during each evaluation session. The logs recorded the position of the avatar, the mouse movement, the position of the cursor, the keyboard input, the task times and the chat messages. The raw log data had to be processed after the evaluation and was divided into logs that had been recorded in the experimentation area and logs that had been recorded during the execution of the scenario. These processed logs then enabled us to create several statistics and to analyze the task performance in a quantitative way.

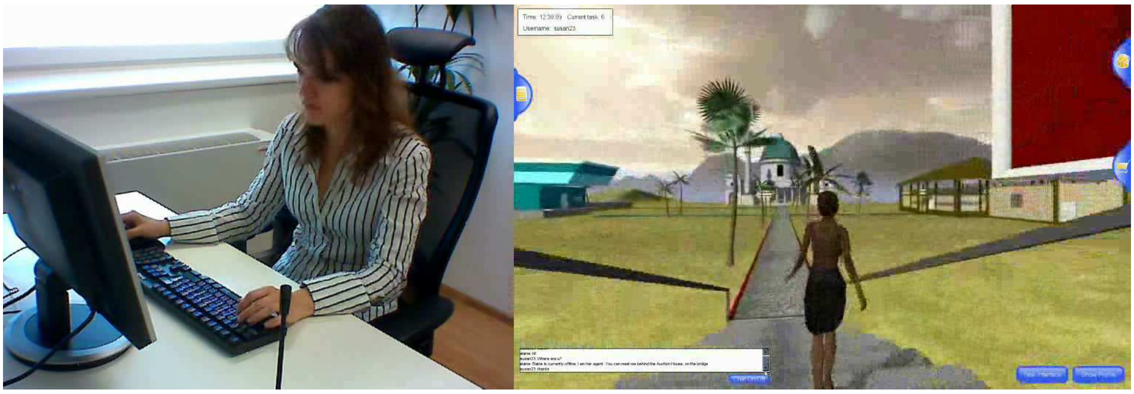

Figure 5.4: A screen shot from a processed split screen evaluation video.

5.4 Results of the Evaluations

The results presented in this Section were derived from the interviews, from the user observations during the evaluation and by analyzing the video footage that was recorded during the test sessions.

User Background

A total of 20 users participated in the evaluations of which eight were female and twelve were male. On average they were 24,95 years old (Standard Deviation (SD) = 4,06). The youngest test persons were 20 years old and the oldest was 36. All were heavy computer users with an average computer usage of 36,7 hours per week (SD = 16,23). Most of the test users, namely twelve, were students studying computer science (five persons), business administration (two persons), pharmacy, journalism, mathematics, psychology and international development (one person each). Another four were working in the Information Technology sector, three test users were working at the university and one test person was working as a secretary. The detailed user data is shown in Table 5.1.

Experience With 3D Virtual Worlds

The majority of the test users did have some experiences with 3D environments. Eighteen persons had already played a 3D computer game in their life, while only two persons had never played a 3D computer game and had no experiences in this regard. The persons that were familiar with 3D computer games had mostly played ego shooters or role playing games. The amount of time people have spent playing these games varies extremely between the different test persons. While some have only tried it two or three times, others have spent several months or years intensively playing these games. The same

Modus	Age	Sex	Weekly computer usage	Occupation
KF	20	M	25 hours	Student
KF	33	M	55 hours	IT Professional
KF	22	W	21 hours	Student
KF	27	W	50 hours	IT Professional
KF	36	M	45 hours	IT Professional
KT	22	M	60 hours	Student
KT	24	M	50 hours	Student
KT	27	W	30 hours	Secretary
KT	27	M	50 hours	University Assistant
KT	23	W	20 hours	Student
MF	27	M	50 hours	University Assistant
MF	25	W	20 hours	Student
MF	27	M	42 hours	University Assistant
MF	26	M	35 hours	Student
MF	21	W	14 hours	Student
MT	26	M	70 hours	IT Professional
MT	20	W	10 hours	Student
MT	24	W	35 hours	Student
MT	21	M	20 hours	Student
MT	21	M	32 hours	Student

Table 5.1: User data.

trend can be observed on the frequency those games are played. Out of the eighteen persons only four persons are still playing computer games, while the other fourteen do not play computer games anymore.

Apart from 3D computer games, people did not have many experiences with 3D Virtual Worlds. Although most of them did know Second Life and had heard of it through the media, only three persons had given it a try. Only two persons did know other 3D Virtual Worlds than Second Life, while the remaining persons had never heard of any other 3D Virtual World.

Travel Behavior

Nearly all test persons use the Internet as a starting point for their travel related information search. About three quarters plan their trips independently via the Internet and also use the Internet to book their travel arrangements. One test person mentioned that the planning process is part of the travel experience and that he especially enjoys the information gathering beforehand. The primary motivations for using the Internet are: easy access to a wide variety of information resources, the possibility to compare different offers online and the possibility of online booking. Among the information resources, the availability of reviews was identified as being important by half of the test users. It is very valuable for them to read about the opinions of other travelers and to have different viewpoints regarding a certain product or destination. Two persons expressed their concerns regarding biased reviews that are put in place by the provider. Therefore, they question such reviews stronger and try to verify that the reviews are independent. An interesting aspect in this regard is the usage of tourism communities. Although nearly all persons actively use the Internet in their travel planning in some way, only two persons participate in an online tourism community, namely Couchsurfing[6]. Some persons were even not aware of the existence of online tourism communities while others are using them when they come across a community during the information search, but they do not actively participate in any.

When asked about travel agencies, thirteen people mentioned that they do not go to travel agencies, while seven persons said that they sometimes visit a travel agency. There was no person that exclusively goes to a travel agency without consulting any further information channels. Among the seven persons a travel agency is consulted for getting additional information, for clarifying complex questions regarding the personal itinerary, for accessing services that can't be accessed otherwise or just for the comfort. A travel agency is rather consulted for longer trips, while shorter trips are planned by the people themselves. Two people even mentioned that they only go into a travel agency for consultation, but do not book the trip there. The trip is then booked on the Internet. The majority of people not visiting a travel agency find it more comfortable to make the travel arrangements online or to call a hotline. For one person the booking is only a "formality" which is best completed in a few steps via a simple web mask. Two persons were saying that travel agencies are more expensive. While the first person just had the prejudice of travel agencies being more expensive, the second person had experienced the price difference herself - the exact same travel arrangement had been 50 Euros more expensive when booked via a travel agency than via a hotline. Another person had the impression that travel agents only mention the positive attributes and might push the customer to buy a certain product.

The personal contact to a professional travel agent is only important for two persons while the other persons do not require this kind of service. For one person the personal confirmation from the travel agent was important and he mentioned that this is a crucial criteria for him when booking a trip. The other person required the assistance of a professional travel agent for her complex travel demands. In contrast, the personal contact

[6]http://www.couchsurfing.com (last accessed 02.05.2010)

to friends or people who have already been to a certain destination is important for half of the test persons. It seems that the faith in friends or people who have already been to a destination is higher than in other people. They are more trustworthy and for some of the test persons the opinion of those people is of high value and helps them to plan their trips.

What is a 3D Virtual World?

Right at the beginning of the pre-interview we asked the test persons how they would define a 3D Virtual World. The question was asked intentionally in the beginning in order to get unaffected answers. For some people it was more difficult to give an answer, while others could easily provide a definition and describe what they understand as 3D Virtual World. Although being different in details, we observed re-occurring characteristics that were mentioned by multiple people. The characteristic that was mentioned by most people, namely twelve, is the ability to walk around in the world with an avatar. Nearly half of the people referred to a 3D Virtual World they already knew (Second Life, MMORPGs). The ability to interact was mentioned by nine persons. The interaction either referred to communication with other users or to the interaction with objects and the world. Another eight people explicitly stated the 3D property again and three of them further stressed that it is “3D and not 2D”. The fact that a 3D Virtual World is a reproduction of the real world and looks like reality was also mentioned by eight people. The remaining characteristics were mentioned by less than a quarter of the test population or by a single person. They included, for example, “Simulation”, “Immersion” and “Commerce”.

In summary, it can be said that among the test population 3D Virtual Worlds are understood as three-dimensional environments that are similar to reality, where it is possible to walk around an which allow users to interact with each other or the environment itself.

Usability Findings

Task Performance

During the evaluations we measured how long it takes to complete a task. The timing for a task was started when the user pressed on the “Start Task” button and the timer for this task was stopped when the task was completed. In the case of a movement task the timer was stopped as soon as the target location was reached, in the case of an action task the timer was stopped as soon as the action was performed and in the case of an information task the timer was stopped as soon as the “Check Answers” button was pressed and all

Difficulty	All Tasks	MT	AT	IT
very easy	219 (61,17%)	101 (72,14%)	64 (64,00%)	54 (51,92%)
easy	84 (23,46%)	30 (21,43%)	21 (21,00%)	25 (24,04%)
normal	42 (11,73%)	8 (5,71%)	13 (13,00%)	16 (15,38%)
difficult	11 (3,07%)	1 (0,71%)	2 (2,00%)	7 (6,73%)
very difficult	2 (0,56%)	0 (0,00%)	0 (0,00%)	2 (1,92%)
Mean	1,56	1,35	1,53	1,91
SD	0,23	0,39	0,64	1,06

Table 5.2: Task ratings.

answers were correct. The completion time of the scenario ranged from 15 minutes and 50 seconds to 31 minutes and 10 seconds with a mean completion time of 24 minutes and 24,75 seconds (SD = 4 minutes and 28,80 seconds).

The post evaluation interview included a part where the users had to rate the difficulty of each task. They were asked to rate the difficulty according to their subjective impression on a 5 point rating scale ranging from very easy, easy, normal, difficult to very difficult. People tended to chose the very easy and easy ratings and only few times a task was rated normal, difficult or very difficult. In particular, of all the ratings 219 tasks (61,17%) were rated as being very easy, 84 (23,46%) as being easy, 42 (11,73%) as being normal, 11 (3,07%) as being difficult and 2 (0,56%) as being very difficult. Note that two tasks have not been rated as they could not be completed due to a system failure. When assigning the values 1 to 5 to this scale, the mean difficulty rating is 1,56 with a standard deviation of 0,23. These low ratings as well as the observations during the evaluations indicate that people quickly learned to use the system and were able to complete the tasks without major problems. The three layered architecture and the verification process caused no significant effect on the system performance and feedback to user actions was given instantly. This suggests that the system was usable in general and that the system architecture had no impact on the user experience.

When analyzing the ratings by task type we can further see that the movement tasks were perceived as most easy (M = 1,35; SD = 0,39). The action tasks were rated a bit more difficult (M = 1,53; SD = 0,64) and the information tasks were rated as being most difficult (M = 1,91; SD = 1,06) - although a mean rating of 1,91 is still comparatively low. Additionally, it can be noticed that the information tasks exhibit a high standard deviation of 1,06. While some people found it easy to complete these tasks, other people had more problems to complete them. The overall task ratings and the ratings by task type are shown in Table 5.2.

When looking at the difficulty ratings on a per task basis (see Table 5.3) some further insights are revealed. The information task that was rated as being most difficult (M = 3,05; SD = 1,10) is task number seven in which the profile of Elaine had to be opened and browsed. The profile had to be opened by performing a right click on Elaine's avatar. Many people had problems to open the profile as they were simply not thinking of the possibility to click the avatar. Furthermore, they rather tried to click the avatar with the left button than with the right button. A lot of people needed help to be able to complete this task. This task also has a high standard deviation of 1,10 indicating that not every person had problems with this task. For some people it was quite natural to perform a right click on the avatar and they could solve the task easily.

The movement task that was rated as being most difficult (M = 1,90; SD = 0,62) is task number six. In this task the user had to walk from the Forum to Elaine's avatar which was standing behind the Auction House. There are three reasons why this task was rated as being this difficult. First, some people did not read the instructions properly and first walked into the Auction House. Second, Elaine was not standing directly behind the Auction House - people had to walk a bit further to be able to see Elaine. Third, Elaine was standing on a bridge in the water. The path leading to the bridge was narrow and had water on both sides - people had problems to walk along this path.

The action task with the highest rating (M = 2,15; SD = 0,77) is task number twelve in which users had to book the hotel room in the Travel Agency. In this task the user had to go into the main room of the Travel Agency, click on the "Search Hotel" button on the user interface and follow the hotel search wizard. While the wizard itself was easy to use for all people, they had problems in finding out how the hotel search interface can be launched (i.e. to locate the button). Until this point in the evaluation most people had not realized that the buttons on the user interface change when a new room is entered. Therefore, they had problems in locating the button and many people tried to interact with 3D objects instead. This behavior might be explained through the previous experience where they had to click on Elaine's avatar to view her profile. They tried to use a metaphor that they had learned previously and from which they knew that it had worked in the past. Like in the profile task, many people needed additional help to complete this task with the hint to look closer on the user interface.

The 3D Virtual World

The responses in the interviews regarding the usability were grouped into positive and negative critique, problems and suggestions for improvement. The following results are based on this categorization and the usability problems that were observed during the evaluations.

Task	Type	Mean	SD	Task	Type	Mean	SD
T1	IT	2,05	0,79	T10	MT	1,20	0,17
T2	MT	1,25	0,30	T11	IT	1,83	0,62
T3	AT	1,60	0,67	T12	AT	2,15	0,77
T4	IT	1,45	0,89	T13	AT	1,25	0,20
T5	IT	1,55	0,58	T14	MT	1,15	0,13
T6	MT	1,90	0,62	T15	MT	1,55	0,68
T7	IT	3,05	1,10	T16	AT	1,50	0,79
T8	MT	1,15	0,13	T17	MT	1,25	0,30
T9	IT	1,50	0,68	T18	AT	1,15	0,24

Table 5.3: Individual task ratings.

In the interviews the 3D Virtual World received slightly more negative critique than positive critique. The positive critique was dominated by statements on the graphics and style of the world. Three quarters of these statements were of a general form where people expressed their joy. They said that they liked the style, that is was pretty and well done. What is interesting about these positive answers is the attitude of some persons towards them. Five persons seemed to have reduced expectations as it is “just a virtual world”. They reduced their judging standards and seemed to be satisfied with the graphics more easily than if it had been a 3D computer game, for example. They said that the style “is completely sufficient for a 3D Virtual World” or that sophisticated graphics “are not needed in a 3D Virtual World”. In the remaining statements people mentioned that the world is not overloaded, is simple and has a clear structure. The other positive critique on the world was about the clarity, the labels and the signs. People said that they could easily find their way and that everything was labeled with big descriptive signs.

The negative critique on the 3D Virtual World is more specific and can be classified more granularly. The input control was criticized most often. Three people would have preferred to use the arrow keys instead of the WASD keys. For two persons the control was too unsteady and too fast. Another person would have liked to control everything with the mouse without using the keyboard at all. The missing interaction with 3D objects, the doors and the graphics were each criticized by one quarter of the test persons. In terms of interaction they would rather have preferred to interact with 3D objects than with the user interface. It was unclear to them where and if it was possible to interact with 3D objects. Furthermore, some people did not understand why there were doors and they said that it was annoying to open them every time. They would have preferred to not have doors at all or that they stay open once they have been opened. In the evaluations it was observed that people could operate and use the doors without major problems in general. However, in some cases they had problems to place the avatar properly in front of the door and sometimes they were outside of the door opening radius in which cases the key press had no effect. Another five people mentioned that the graphics and the style of the 3D Virtual World was too simple and rudimentary. They would have liked it to be more fancy with additional objects and better graphics.

These results show that graphics and design are properties that cannot be planned perfectly and are perceived differently by different persons. While some persons criticized the emptiness and the style of the world, other people preferred the clear and reduced design. This is also true for other parts of the 3D Virtual World. Some people mentioned that the paths between the buildings are too long and that it takes too long to get from one point to another. In contrast, other people had a completely oppositional view. In their eyes the lengths of the paths were just fine and they stated that one could get around quick and easily. The same applies to the doors which were perceived as unnecessary and annoying by some people, while other people did not have any objections against them.

The 2D User Interface

The user interface received twice as much positive critique than negative critique. The majority of the positive statements were attributed to the masks and dialogs (i.e. search mask, payment wizard, etc.). People said that the dialogs were simple, well structured and could easily be used. It was noticeable that people had certain standards which they were used from dialogs, masks and web forms in general. Since the dialogs in Itchy Feet were designed according to usability guidelines and best practices, the expectations of the users were met. Therefore, the test users had no problems with the usage of the dialogs and judged them as being up to the same standards they are used to. Similar to the positive critique on the 3D Virtual World, the other positive statements on the user interface were of a general form. People said that they liked the user interface - the symbols, the big buttons, the coloring and the clarity of the interface were perceived as positive attributes.

The negative critique and problems with the user interface mostly revolved around the changing buttons. It was criticized that the change of the buttons was not noticed. People paid attention to what was going on in the middle of the screen and did not realize when something happened in the right corner where the buttons are placed. It was also unclear to them when the buttons change, the arrangement of the buttons was not logical for one user and one person criticized that the style of the buttons is not in line with the 3D Virtual World.

Suggestions for Improvement

We also asked the test persons if they had any suggestions for the improvement of the system. They made several suggestions of which the most were related to the 3D Virtual World and the user interface. In the 3D Virtual World people would prefer to have additional objects like plants, computers or pictures on the walls. They would like the environment to be more immersive, that more information is provided and that the possibilities of the 3D Virtual World are utilized better. Some people would like to have a function to avoid the paths and to directly jump to a certain location. This could be achieved by the introduction of a clickable mini map where one gets teleported to the location that was clicked on the map. The removal of doors was suggested by one person and another person mentioned that she would like to have additional navigation helpers like a 3D arrow pointing at the target location.

For the user interface people had different suggestions. Three people said that it would be a good idea to have additional cues for the change of a button. The buttons could flash for some seconds whenever they change or a notification could be displayed upon a button change. The request to have a mini map was also mentioned three times. Among the remaining suggestions for improvement three were related to the auctions. People suggested to have a counter that shows the remaining time, to get a notification when an auction starts and to automatically delete the value from the input box after the bid was submitted. Further suggestions included a search functionality for finding users, the addition of sound and acoustic signals and a longer tutorial that covers more topics.

Interaction Design

The test persons habits regarding personal interactions and the usage of communication facilities in their travel planning were presented at the beginning of this Section. We saw that tourism communities are used sparingly, travel agents are usually not consulted and trips are planned individually via the Internet.

In the evaluations users also had to research information in the Forum where they had to browse to a thread and read several postings. The navigation in the forum interface could easily be performed by all test users, but some persons did not read the entries properly and had to re-read them again to be able to complete this task. In the communication tasks they had to talk to another user and to a travel agent that were both played by another project member. We observed that people were quite direct when talking to these other users. For example, in the task where the travel agent had to be consulted, the goal was to find out which hotels are recommended. People then just stated a question of the form “Which hotels are recommended?” and one third did not use an introductory statement like “Hello”. Three persons even just entered the text in a keyword like style “recommended hotels” and did not formulate a question. However, this can probably be attributed to a misunderstanding of the task description as some people thought that a travel agent is an autonomous software agent.

An interesting result of our study were the reactions to the functional separation of the 3D Virtual World. The functional separation is the separation of functionality based on the physical space in the 3D Virtual World. When asked about the functional separation nearly everyone said that it was fine and that they had no problems. However, people were only referring to their experiences in the scenario and acknowledged that the functional separation worked well during the execution of the scenario. We then had to further query them and made clear that we wanted to have their opinion on the functional separation in general. Some people then stalled a little bit and had to rethink their opinion. It turned out that some people changed their opinion and then rejected the functional separation. However, the majority of the people (three quarters) still liked the idea and would appreciate this separation in a real application.

When looking at the reasons for the approval people mentioned that they like the clarity of this separation, that the interface would be too overloaded otherwise and that it created a playful character. The people who rejected the idea would prefer to have all the functions in one place and criticized the long time it takes to get from one building to the another. This disadvantage could be circumvented by letting the user jump from the exit of one building to the entry of another building. Such functionality could be implemented in a future version and would further contribute to the usability of Itchy Feet.

e-Commerce Facilities

While all people did participate successfully in the auctions, the evaluations did reveal some usability issues. It was unclear how long the auction will last and the different steps of the auction (going once, going twice, sold) were not perceived by all people. The current status of the auction was displayed on the auction panel and the bidding and progressing actions were further visualized via animations (hand raising gesture for the bidding, waving gesture for going once, going twice and sold). However, during the evaluations we observed that people sometimes positioned the avatar in such a way that the auctioneer and/or the bidding agent were not seen from this position. As a consequence they were not able to see the gestures of the other avatars. Similarly, other people were focused on the auction interface to such a degree that they did not notice what was going on around them and also were not able to see the gestures. This suggests that it is necessary to provide essential information at a location that is within the field of vision of the user. If information is communicated via the 3D space only, the user might simply not be able to see it because she is looking in a different direction. In such a case it is important to also display the information on the user's screen to bring it to her attention.

Among the test users one half had already participated in online auctions (all of them on eBay[7]) while the other half had never bought a product in an online auction. The prevalent reason for not buying a product in an auction was that it just had not come up, but two persons stated that online auctions are not trustworthy. When asked about auctions in the tourism domain, thirteen people stated that they found the idea interesting and that they would buy a tourism product in an auction. The personal curiosity and the opportunity to buy a product at a lower price were mentioned as motivation. Five other people were uncertain about buying tourism products in auctions and two persons clearly stated that they would not participate in an auction to buy a tourism product. They had the concern that a product bought in an auction might not conform to the product description and they did not see any advantages over buying a product at a fixed price.

When we touched the subject of 3D products in the interviews, people seemed to get very interested upon this idea. We had started their imagination and they were beginning to think about this concept. The reactions were mostly positive and people appreciated this concept. Although people were generally interested in replications of hotel rooms and the like, during the discussions it turned out that they are even more interested in the replication of the whole environment. The view outside the hotel, the shops and restaurants around the hotel and the location of tourist attractions and subway stops are of even higher importance to them. Some people mentioned that they would have concerns on the authenticity of those products, i.e. that they appear more beautiful than they are in reality. However, this concern can never be avoided regardless of the presentation type as every image or video can be forged as well. Only three people were negative about 3D products, but rather from a personal point of view ("I don't need it") and not about the concept in general.

Input Control

Similar to the rating of the tasks in Section 5.4, we also asked the users to rate the difficulty of the input control on a 5 point rating scale. They were asked to rate the difficulty in three different settings.

- *Question 1:* How would you rate the difficulty of controlling the avatar in the open

[7]http://www.ebay.com (last accessed 02.05.2010)

Mode	Q1		Q2		Q3		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
All	1,4	0,36	1,55	0,58	1,65	0,45	1,53	0,46
KF	1,4	0,3	1,6	0,3	1,4	0,3	1,47	0,27
KT	1,6	0,3	2	1	2	0,5	1,87	0,56
MF	1,6	0,8	1,6	0,8	2	0,5	1,73	0,64
MT	1	0	1	0	1,2	0,2	1,06	0,07

Table 5.4: Input control ratings.

space?

- *Question 2:* How would you rate the difficulty of controlling the avatar inside the buildings?
- *Question 3:* How would you rate the difficulty of walking through the doors?

The results of this rating are displayed in Table 5.4. From these results we can see that the ratings are low in general and are slightly different between modes. The mouse mode in combination with the third person view received the best ratings (M = 1,06; SD = 0,07). The keyboard mode in combination with the first person view was rated a bit worse (M = 1,47; 0,27). And the mouse mode in combination with the first person view (M = 1,73; 0,64) as well as the keyboard mode in combination with the third person view (M = 1,87; SD = 0,56) received the worst ratings. What is interesting about the last two modes is the high value of the standard deviation. Apparently, these modes were rated as being difficult by some test persons, while other persons rated them as being equally difficult to the other input modes. Note that these results are only based on the subjective ratings of the test persons and have not yet been confirmed in a controlled quantitative experiment.

When asked whether they had already used the type of input control in which they had performed the evaluation, most people said that they had already used it. However, it seemed that people did not pay attention to the details that differentiated the input modes. They confirmed that they had already used this type of input control, but then could not tell whether the exact same keyboard mapping had been used, whether the view had been controlled via the mouse or if a first or third person view had been employed. This suggests that the different input modes do not influence the usability. We could also observe that people did quickly get familiar with the input controls. Persons who had massive problems in the beginning, quickly learned to control the avatar and rated the input controls as being easy after the evaluation. This further stresses the insight that the type of input control does not affect the usability and that any mode can be chosen for a 3D Virtual World.

Discussion

The evaluations showed that people could complete the tasks easily in general and the environment remained responsive despite the interconnection with the Multi-Agent System. Some functions proved to be highly usable, while the evaluations identified areas for improvement of other functions. Especially the user interface and the adoption of familiar 2D input dialogs proved to be effective and indicate that 2D controls shall be employed in 3D Virtual Worlds. The study also showed a high need for interaction with 3D objects. Once people had learned that they can interact with 3D objects, they rather tried to interact with 3D objects than use the 2D controls if they did not know how to complete a task. This behavior was observed in the hotel search task in which users where required to press the “Search Hotel” button to open the hotel search interface. Many of them did not notice that there was a “Search Hotel” button on the user interface and they tried to launch the interface via an interaction with the 3D Virtual World. It was interesting to observe that they tried to interact with objects that were most likely related to this task. Therefore, they tried to click on travel catalogues that were available in a brochure rack and they even went behind the payment desk where they tried to interact with a computer terminal. This suggests that people stick to the same metaphors they are used to from the real world and that real world metaphors can be employed to effectively direct the user’s attention towards the appropriate interactive elements. In terms of orientation in the environment, the usage of real world orientation metaphors such as guide posts and signs also proved to be an effective means for orientation. Although the lack of a map functionality was criticized by some participants, orientation problems were not observed and people could find their way quick and easily. Therefore, in the case of small sized 3D Virtual Worlds, such as ours, the inclusion of guide posts and signs can be sufficient to enable efficient wayfinding and orientation.

The auctions showed that it is important to provide information that is relevant to the user independent of the user’s current view of the 3D Virtual World. During the auctions the users sometimes positioned the avatar in such a way that the actions of the other avatars (hand raising for bidding, waving for accepting a bid) could not be observed. It was therefore important to also display the current state of the auction on the user’s interface in order to keep her informed about the current price. Additionally, this state change on the user interface needs to be communicated to the user in a clear and effective way. During the evaluations users were sometimes focused on the 3D Virtual World to such a degree that they did not notice changes on the user interface like the appearance/disappearance of buttons. In this case a visual cue (e.g. flashing button) would have been necessary in order to inform the user of the change on the user interface. This especially applies to the concept of separating the functions by the physical area. Many users did not realize that the buttons on the user interface changed when they entered a new room, because they were focused on the 3D Virtual World. A visual cue would have been necessary to better communicate this state change to the users. Nevertheless, the concept of separating the functions by area was well received by the majority of the test users. Those who favored the concept appreciated the fact that the user interface remained simple and clean. Those who rejected the concept would rather prefer to have all the functions available at once, but they also approved that the separation was not problematic in the evaluations and worked well in the context of the scenario.

Another interesting result is the diverging user opinion on non-tangible properties such as graphics and design. This indicates that the design of the environment should be strongly oriented towards the target user group and that end users should be integrated in the development process from the beginning. The possibility to enrich the environment with 3D products such as hotel rooms and tourism destinations was appreciated by the test users as well. 3D products in the tourism domain might be a valuable new type of product presentation and could help users when making their buying decision. The results from the interviews show that the replication of complete tourism destinations is slightly favored over the exclusive replication of hotel rooms, but further research in this direction is necessary to fully understand the users needs.

Finally, in the evaluations the user population was split into four groups and every group performed the evaluation with different input control settings. The input controls were distinguished by the input control used (keyboard/mouse) and the avatar view (first person/third person). The results from the questions on the input control modes as well as our observations during the evaluations indicate that the type of input control does not have a significant effect on the ability to move around and navigate in the 3D Virtual World. However, this result still needs to be verified in a future study in order to determine if the input control has an effect on the performance of the user or not.

5.5 Summary

In this Chapter we presented the empirical user evaluation that had been conducted in Itchy Feet and provided details on how evaluations can be conducted in 3D Virtual Worlds. We reviewed related literature on evaluating applications in Virtual Reality environments and 3D Virtual Worlds and introduced an evaluation procedure consisting of user task analysis, expert guideline based evaluations, formative evaluations and summative evaluations. These types of evaluations are used in our proposed process model as well. This Chapter focused on the application of formative evaluations and we showed how our evaluation was designed, how an engaging evaluation scenario was created, what the evaluation setup looked like and how the evaluation sessions were performed.

The four goals that were addressed in the evaluation (usability, interaction techniques, e-Commerce facilities, input controls) were introduced and the results were presented and discussed in detail. We saw that the environment was usable in general and that all the 20 test persons were able to complete the scenario. Among other findings the results provided insights on the functional separation in the world (which was favored by the majority of test users), showed that 2D interface elements worked well but that users rather try to interact with objects in the world when presented with unknown situations, provided information on e-Commerce aspects in tourism (3D products as a possible addition, proper integration of auctions), showed that simple and real world navigation metaphors can work in a small 3D Virtual World and illustrated that the users opinions diverge on non-tangible characteristics such as the design of the world.

CHAPTER 6

Conclusion & Outlook

This thesis established a new 3D e-Tourism environment and explored 3D Virtual Worlds from an application building perspective. A process model for the development of applications in 3D Virtual Worlds was created and the application of 3D Virtual Worlds to the tourism domain was studied.

A design-science research approach was taken to develop the results presented in this thesis. The starting point for this research was the creation of an agent-based 3D e-Tourism environment that provided us with a testbed for conducting research in 3D Virtual Worlds and demonstrated the feasibility of implementing 3D Virtual Worlds as Virtual Institutions. The created environment addressed the topics of the second research goal. The goal of providing an environment that enables interactions and trade among the participants was addressed through the development of a trade infrastructure in which business processes are carried out by software agents and trust is ensured through Electronic Institutions. In order to enable the establishment of a tourism community, several essential community facilities were implemented. This includes user account and user profile management, public and private chat facilities and the integration of a forum into the 3D Virtual World. The possibility to integrate disparate information sources in the environment was achieved through the agent-based architecture. Agents are used to provide access to fixed price tourism products, to products that are sold in auctions and to tourism information that is stored in an external Web forum.

The 3D e-Tourism environment then served as the basis for an empirical user evaluation in order to investigate tourism in the context of 3D Virtual Worlds and to address the topics in the third research goal. A qualitative approach was taken to identify the users opinions and attitudes towards the environment. The evaluation was designed with respect to a real world tourism use case in order to provide users with a realistic usage experience. A scenario with eighteen tasks was created in which users had to research information in the environment, talk to other users and book two hotel rooms, one in an auction and one for a fixed price. The usability of the environment was assessed and the successful execution of the evaluations demonstrated that the environment is usable in general and can be used by novice users. Some usability problems such as not noticing the change of 2D user interface elements were identified and provide opportunities for further improvements and future research. The interaction and communication with other users worked well during the evaluations. However, no elaborate conversations emerged and the test users rather limited the dialogs to the information they had to find out in the respective task. The concept of separating the functions by area was not directly apparent to the users, but once they had learned about the concept they could handle it well. The majority of the test users later also confirmed that they liked the concept and that it resulted in a clean and clearly laid out user interface. The evaluations showed that the test users would be interested in the provision of 3D tourism products, whereas the replication of whole tourism destinations was favored over the replication of single hotel rooms or guest houses. The test users did not have experiences with buying tourism products in auctions, yet they all successfully participated in the auctions during the evaluations. Some of them stated that they would be interested in buying tourism products in auctions as they see a possible price advantage over fixed price products. However, further research would be necessary to identify what types of tourism products are suited for auctioning and what the exact needs of the users are. Finally, we found out that real world navigation metaphors such as guide post and signs can be sufficient navigation and orientation means in a small 3D Virtual World and that different input control modes (first person/third person, keyboard controlled/mouse controlled) do not seem to have an influence on the ability to navigate around in a desktop based 3D Virtual World.

The experiences that were gained while building the 3D e-Tourism environment and the aggregated knowledge of related works from the fields of 3D Virtual Worlds, Virtual Reality and software engineering finally led to the formulation of the process model for engineering applications in 3D Virtual Worlds. The process model addresses the topics that were formulated in the first research goal. It is holistic and provides guidance throughout the whole timeline of development. It is not dependent on a certain 3D Virtual World technology, but can be used for the development of any desktop based 3D Virtual World. And it includes activities and tasks that enable project members who are not familiar with 3D Virtual Worlds to get engaged in the development as well. The process model encompasses eight different disciplines and the development takes place in iterative cycles in order to create an application that is usable and addresses the users needs. The introduction discipline includes activities to make project members familiar with the concept of 3D Virtual Worlds and to help them understand the possibilities and limitations of this technology. In the requirements discipline the needs of the users are identified and a strong focus is placed on the identification of tasks that are relevant to the users. The abstract design discipline deals with the development of technology independent designs of the 3D Virtual World and the user interfaces. They provide first and quick impressions on the appearance of the application and serve as a decision guidance for the selection of the 3D Virtual World technology. This selection is performed in the 3D Virtual World selection discipline in which the most suitable technology with respect to the requirements and the users needs is identified. In the realization discipline the application is created whereas the modeling of the 3D content and the writing of the source code can take place in parallel. Depending on the current stage of development, the application is evaluated in the evaluation discipline either in expert guideline based evaluations, in formative evaluations or in summative evaluations. The deployment discipline includes activities for deploying the application in the production environment and for making it accessible to end users. In the last discipline, the project management discipline, the necessary features of the application are determined and the development is planned and managed. These disciplines encompass all the required activities that are necessary for developing applications in 3D Virtual Worlds and, when conducted according to the process model, should result in an effective and usable 3D Virtual World application that addresses the users needs and fulfills the users expectations.

6.1 Directions for Future Research

In terms of the process model the question arises how the suitability and utility of the model can be evaluated. The credibility of a process model is typically established through the application of the process model in case studies. The researchers are then able to learn about the utility of the process model in a real world context and are able to adapt and improve the process model according to the gained experience. A possible direction for future research therefore is the application of the process model in case studies. This would enable us to further verify the utility of the model and to identify potential weaknesses. A more formal type of evaluation would be the assessment of the process model through experts from the software engineering and 3D Virtual World domains. A rating system could be created according to which these experts rate the quality of the process model. Alternatively, the opinions of the experts could be captured via expert interviews. An even more rigorous approach would be the direct comparison of different process models through the competitive creation of the same application. Based on the same set of requirements, multiple teams could develop an application according to different process models. The development processes are studied and the final applications are evaluated against each other with respect to the requirements. In theory such a rigorous evaluation design should yield clear results and unambiguously capture the advantages and disadvantages of the process model. However, in practice the execution would be extraordinary laborious and it would be difficult to design the evaluation in such a way that the results can clearly be traced back to the employed process model.

In terms of the 3D e-Tourism environment, directions for future research include the extension and further study of tourism related topics in the environment. A possible direction is the integration of 3D products in the environment which was identified as a promising additional feature in the evaluations. It would then be possible to evaluate 3D products in a practical setting and to study if 3D products help users in getting a more detailed impression of the presented product. While during the evaluations the proper functionality of the communication facilities was validated and users already had to communicate with two other characters, the environment should further be evaluated with multiple test users simultaneously. This would enable us to test the environment under a high load in order to see if it scales well and would make it possible to study the interaction and collaboration among users. It would be interesting to see if the 3D Virtual World facilitates the communication between users, makes it easier to meet new people, increases the social presence and has an effect on the perceived human warmth. Furthermore, the environment could be extended with additional community features such as a reputation system or collaboration functionalities and support for the on-trip phase could be added as well. A mobile client application could be created that enables the user to connect to the 3D Virtual World during the trip. This would allow the user to participate in the community right from the destination, the travel agent could be consulted for advice and information on local events could instantly be shared and made accessible to other community members.

The separation of functions by area in the 3D Virtual World provides another area for further study. The evaluations showed that this concept was favored by the majority of the test subjects indicating that this could be a promising topic for future research. The concept would have to be evaluated with a larger number of users in which different variants of this concept should be compared with each other. In a similar fashion, the relationship between 2D and 3D user interface elements needs to be studied as well. In the evaluations we saw that it is necessary to provide important information directly to the user on the 2D interface and that it is necessary to make the user aware of information changes (on the 2D interface as well as in the 3D Virtual World). It would be interesting to research the properties of 2D and 3D user interface elements and to identify and categorize interaction sequences that are suited best for the respective interface metaphor. Similar to the 3D Virtual World criteria catalog (Appendix A), a catalog could be created that provides guidance on choosing the appropriate interface elements for a given interaction sequence.

The underlying framework of the 3D e-Tourism environment as a general Virtual Institution based e-Commerce framework provides additional potential for future research. A possibility would be the implementation of additional e-Commerce scenarios such as a virtual market or an auto show to further study the combination of e-Commerce and 3D Virtual Worlds. Additionally, the application of the framework beyond e-Commerce could be considered. For example, e-Learning or e-Government might be promising domains in which Virtual Institutions could be utilized to communicate knowledge in a familiar environment and to ensure trust through the rigorous specification and enforcement of the institutional rules. In this regard, we currently aim at the collaboration with researchers from the Artificial Intelligence Research Institute (IIIA) in Barcelona, Spain. They are working on the automatic generation of 3D Virtual Worlds out of Electronic Institution specifications based on shape grammars (Trescak et al., 2010). So far, they implemented a tool that enables the automatic creation of a static 3D Virtual World. As a next step they intend to make the 3D Virtual World dynamic and would like to utilize the middleware layer of our framework for the real time message exchange between the Electronic Institutions and the 3D Virtual World. This collaboration will provide us with insights on the application of the framework in a different setting and will further contribute to our understanding of building Virtual Institutions.

APPENDIX A

The 3D Virtual World Criteria Catalog

The 3D Virtual World criteria catalog is a collection of 3D Virtual World characteristics. It was introduced as part of the process model in Section 3.2, where it is used during the familiarization with the technology and the selection of the 3D Virtual World. The catalog provides a collection of those characteristics that are most relevant in the context of 3D Virtual Worlds. It helps to understand the nature of this technology and serves as a basis for the classification of different 3D Virtual Worlds. This catalog is based on a revised and extended version of a criteria catalog that was presented by Baumgartner (2008). Those characteristics that are mainly relevant for the integration of the application into an existing online 3D Virtual World are marked with an “O”.

Barriers to Entry

Hardware Requirements

This characteristic captures the minimum hardware requirements of the user’s computing device that are necessary to execute the 3D Virtual World application. The computing power can vary greatly from device to device and it is a huge difference whether the application is executed on a desktop computer, a laptop or a mobile phone. As a consequence, the minimum hardware requirements define which user groups can be accessed and the way in which the application can be executed.

Software Requirements

This characteristic captures the minimum software requirements of the user’s computing environment that are necessary to execute the 3D Virtual World application. This encompasses the supported operating systems, additional software components that have to be installed as well as any additional libraries on which the application depends.

Language Support

The localization of a 3D Virtual World and the number of different languages it supports is another crucial barrier to entry. Depending on the language support, entire user populations can be excluded from the 3D Virtual World. For English native speakers this especially becomes apparent when looking at the Asian market, where several online 3D Virtual Worlds exist that are only available in Chinese, Korean or Japanese.

Client Traffic

The client traffic criterion characterizes the amount of Internet traffic that is generated on the user's computer by the 3D Virtual World client. It defines the minimal connection speed that is required for a smooth execution of the 3D Virtual World.

Learning Curve

There is typically a certain learning curve imposed by 3D Virtual Worlds until users are able to move around and understand the spatial properties of the environment. The learning curve defines how quickly users are able to learn the required concepts and how long it takes until they are ready to participate. As such, the learning curve has an influence on the user's willingness to participate and is an additional factor that can influence the participation of users.

Geographical Limitations (O)

The provider of an online 3D Virtual World might impose certain limitations on the geographical regions from which the world can be accessed. Similar to the language barrier, this limitation can restrict the access to the 3D Virtual World for entire user populations.

Subscription Cost and Cost of Participation (O)

In some cases a one-time or regular subscription fee has to be paid to be able to access the 3D Virtual World. This especially applies to online 3D Virtual Worlds and 3D computer games, where a subscription model might be used to finance the environment. In addition to initial or regular costs for accessing the world, the participation in the world itself might impose certain costs. This could include entrance fees to events or certain areas, costs for additional functions or costs for the clothes of the avatar.

Avatar Features

Movement

The mobility of the avatar in the 3D Virtual World is determined by the movement commands that are available. While in certain worlds the avatar can only be moved to fixed and pre-defined positions, other worlds enable a completely free movement including teleportation and flying. The movement can be described along the following movement dimensions: *walk*, *run*, *jump*, *fly*, *swim*, *teleport* and *drive*.

Look

The appearance of the avatar and the possibilities to customize the look of the avatar are captured in this category. The appearance and especially the personal customization of the avatar has a significant influence on the degree of identification with the virtual character. There are three dimensions along which the look of the avatar can be described: *body*, *clothing* and *accessories*.

Health and Death

In a 3D Virtual World the concept of health and death describes whether damage can be inflicted on the avatar or not and the consequences that are perceived when the health level drops below a certain limit.

Gestures

In a 3D Virtual World, the support of gestures extends the repertoire of communication commands between users and can convey information on the activities the person behind the avatar is currently performing. During a communication gestures might be used to emphasize a statement such as a waving gesture to say good bye or they might be used to express ones feelings such as a jumping gesture to express joy. Additionally, gestures can provide information on the current activities of the avatar. A sleeping gesture might be used to indicate that the avatar is inactive and a writing gesture might be used to indicate that the user is currently typing some text.

Inventory

The inventory of the avatar is comparable to the home folder of a user on a Windows or Linux system. It holds the personal items of the avatar and provides access to a persistent data storage where items are stored permanently. The properties of an inventory include the content types that can be stored, the size restrictions and the access policies to the inventory.

Use of objects

This characteristics describes the type of objects that exist in the 3D Virtual World and how they can be used by the avatar. The usage possibilities can range from objects that are simply picked up to objects that can be used by the avatar to objects that can be mounted by the avatar. The first category mostly includes objects that will provide a benefit to the avatar such as a health kit or a gold coin. The second category encompasses objects that the avatar can hold in its hands and which might additionally be operated by the avatar such as weapons. The mounting of objects in the third category refers to objects which the avatar can utilize to move around in the world. This includes objects such as cars or bicycles that enable the user drive around in the environment.

Avatar portability

Avatar portability defines the support of transferring an avatar from one 3D Virtual World to another. It consists of the export and import functionalities that are available and defines the scope of data that can be exported and imported.

Graphics

Graphical Features

The graphical features determine what can be accomplished in a 3D Virtual World from a visual perspective. The graphical features encompass the rendering capabilities of the engine and the visual effects that are available (e.g. particle effects, weather effects).

Look And Feel

The look and feel is a subjective measure describing how the environment is perceived. The degree to which users feel comfortable in the 3D Virtual World is mostly influenced by the look and feel. This, in turn, has an influence on the personal enjoyment and the length of a stay in the 3D Virtual World.

Multimedia Support

The access to multimedia-based information sources is captured within this characteristic. It encompasses the types of multimedia information that can be viewed, the formats that are supported and how the information sources can be integrated in the 3D Virtual World. This can range from audio and video streaming from external websites to the direct upload of content into the environment.

Performance

Load Time

The load time is characterized as the time span between starting the 3D Virtual World application and being able to participate in the 3D Virtual World. This also includes the time that might be required to enter login credentials or the time it takes to specify the location at which the avatar should enter the 3D Virtual World.

User Maximum

The maximum number of users defines how many users are able to participate concurrently in the world and which effect the number of users imposes on the performance of the 3D Virtual World.

Lag

In client/server based 3D Virtual Worlds a delay in the client/server communication might occur resulting in a slow-down on the client computer. The actions of the user are no longer processed in real time and the state of the world is no longer updated in real time. As a consequence the avatar starts to move jerkily and changes in the world are perceived jerkily. This can be caused by problems in the communication channel as well as by an overload on the server resulting from too many connected clients or a poor server infrastructure.

Modification and Customization

Scripting

This category refers to the availability of scripting languages in the 3D Virtual World. Scripting languages are often included for the quick and simple definition of the program logic. They provide powerful methods to extend the world with custom programs and can be classified by the scope of the provided functions, the execution speed and the power of the language constructs.

Source Code

This characteristic describes if and how the source code of the 3D Virtual World can be modified. The possibility to change the source code of the 3D Virtual World provides great flexibility and allows the developers to change and adapt any aspects of the world according to their needs.

Content Creation

The content creation characteristic defines how the content is created for the 3D Virtual World. Typically, we can distinguish between content creation inside the 3D Virtual World and the import of models into the 3D Virtual World. In the latter case, the models are created outside the world with a dedicated modeling application and are then imported into the environment. The supported formats and the maturity of the importer (i.e. that models are not distorted during the import) are crucial criterions in this case. When the content is created directly in the world, the features and the functionality of the provided editor become important. Additionally, the support of export functionalities might be of interest in this case as it enables the possibility to store and backup the models independent of the 3D Virtual World.

User Interaction and Community

Communication Facilities

The communication facilities in a 3D Virtual World define in which ways users are able to talk to each other. The most basic form is the text chat where messages are typed in by one user and read by one or more other users. Private messaging systems are another form of text-based communication that enable the asynchronous communication between users. More sophisticated communication functions include support for voice-based and video-based chat.

Profile

The user profile contains all the personal information of an user and enables other users to get an impression of the personality and interests of that user. The support of user profiles can be distinguished by the type and amount of information that can be provided and by the support of privacy settings to control the visibility of this personal information.

Collaborative manipulation

The collaboration between users in the community determines which kind of tasks can be collaboratively performed inside the environment. This criterions is especially important for collaborative applications that have the goal to create a collective workspace for distributed members of a team. The collaborative manipulation can range from the collective creation of objects to the collaborative writing of a document.

Object sharing

The object sharing defines how objects can be shared among the members in the community. This includes the access policies that can be set for objects - who is able to access which kind of objects in which ways. And also encompasses how objects can be exchanged between members.

Community Size and Activity (O)

This criterion captures the size and activity of the community and is an indicator for the popularity of the 3D Virtual World. The size itself can not be used as the sole descriptor of the community as a community might include inactive members for the most part. The activity therefore captures the activity of the members and describes how lively the community is. An active community can be an important factor when deciding upon the 3D Virtual World technology.

Commerce

Trade

The trade criterion captures the support of trading functions in the 3D Virtual World. They enable the trade of products between different parties in the environment and define how the trade can be conducted, what kind of items are tradable and who is allowed to engage in this trade.

Marketplace (O)

The marketplace defines the framework in which the trade takes place. Marketplaces are distinguished by the types of products that can be traded and the location of the marketplace. The marketplace may support the trade of virtual products that are used in the world as well as real world products. Additionally, the marketplace can either be internal or external. On an internal marketplace the trade directly takes place in the 3D Virtual World, while on an external marketplace the trade is conducted outside the 3D Virtual World.

Monetary System (O)

The trade of products is enabled through the monetary system of a virtual world. Typically, 3D Virtual Worlds have an in-world currency with which products can be paid. The currency can either be exchanged for real world money or earned inside the world. Different types of currencies might be available within one world to distinguish between currency that was exchanged and currency that was earned. The exchange from in-world currency back to real world money is another important aspect that is necessary for being able to make money in a world.

In World Situation (O)

Content Limitation (O)

The provider of the 3D Virtual World might impose a limitation on the amount of content that is created within the world. This can greatly constraint the application development and it is important to understand the content creation policy before any development activities take place.

Ownership and Copyright (O)

If the application is provided through a third party 3D Virtual World, it is necessary to understand the ownership and copyright of this world. It defines who the owner of the created or uploaded content is and whether the copyright remains by the creator or is automatically transfered to the provider. Furthermore it defines how well the copyright and property is protected in the 3D Virtual World and if objects can be copied, stolen, destroyed or deleted.

End User License Agreement (O)

When participating in a third party 3D Virtual World, the user might need to sign an end user license agreement that defines the terms and conditions of the world provider. For application developers this agreement is of interest as well as the terms and conditions need to be in line with the policies of the application developers. Furthermore, the end user license agreement might pose an additional barrier to entry for certain users who are not willing to participate in this world under the given terms.

Privacy (O)

The privacy is related to the protection of private and personal data within the 3D Virtual World. This encompasses the personal data of users as well as data that is stored in the 3D Virtual World as part of an application. The privacy defines how well the data is protected, which kind of means are incorporated by the world provider to protect the data and in which ways privacy settings can be controlled by the user or application developer.

Miscellaneous

Security

This characteristic captures the security of the 3D Virtual World with respect to attacks from a third party. This includes attacks on the hardware and software that execute the 3D Virtual World, attacks on the client computer through which the 3D Virtual World is accessed and attacks on the traffic between the 3D Virtual World and its users.

Documentation and Support

The documentation and support capture how well the world is documented and how difficult it is to get help on specific topics. The documentation is typically found in the following sources: *official website*, *help*, *blogs*, *forums* and *wikis*. A distinction has to be made between officially provided documentation and user generated documentation. Typically the official website will offer documentation and help on how to use the 3D Virtual World including tutorials, How Tos and Frequently Asked Questions (FAQs). Additionally, there might be an official support helpline which offers personal help via email or telephone.

APPENDIX B

List of Questions for the Selection of the 3D Virtual World in Itchy Feet

The questions that were used for the selection of the 3D Virtual World in the Itchy Feet project are presented in this Appendix. As the 3D Virtual World criteria catalog had not been established at the time of the selection, the questions were organized more generally according to the ISO 9126 standard on software product quality (International Organization for Standardization (ISO), 2003). We selected those categories that were relevant in the scope of our work including portability, usability and functionality. The questions in the upcoming Sections are organized according to these categories.

Portability

Adaptability, Installability

Definition (Adaptability). The capability of the software to be modified for different specified environments without applying actions or means other than those provided for this purpose for the software considered.
Definition (Installability). The capability of the software to be installed in a specified environment.

Quality Needs	Evaluation Procedure
The software should run on all three major operating systems (Windows, Mac OS X, Linux)	Reading the manuals.
The worlds should include an easy to use installation wizard.	Trying to install the products.

Questions

- Is the Windows operating system supported?
- Is the Mac OS X operating system supported?
- Is the Linux operating system supported?
- Are other operating systems supported as well?
- Is there an install shield or install wizard?
- What is the installation procedure like?

Usability

Understandability

Definition. The capability of the software product to enable the user to understand whether the software is suitable, and how it can be used for particular tasks and conditions of use.

Quality Needs	Evaluation Procedure
It must be easy to identify the available functions in short time.	Reading the online resources and manuals.
There must be a general overview of these functions (e.g. in which programming language they can be used, what exporters are supported, ...)	

Questions

- Is there a feature list?
- Is there something like a general overview?
- Is this general overview informative?

Learnability and Operability

Definition (Learnability). The capability of the software product to enable the user to learn its application.

Definition (Operability). The capability of the software product to enable the user to operate and control it.

Quality Needs	**Evaluation Procedure**
It should be easy to learn and understand the mechanisms of the framework.	Learning to operate the software with tutorials, demo programs and tools.
There should be some editors and tools for helping to understand the way things work.	
The learning curve must not be to steep.	

Questions

- Is there a project documentation?
- What is the quality of this documentation?
- Is there a search functionality?
- Is it easy to find relevant information?
- Are there tutorials?
- Are there more than 10 tutorials?
- What is the quality of these tutorials?
- Are there demos or demo programs?
- Is there an API specification?
- Is the API nice to read (in terms of layout, structure and colors)?
- Are there tools, editors or even a development studio?
- What is the quality of these tools (are they user friendly, easy to operate, ...)?

Attractiveness

Definition. The capability of the software product to be liked by the user.

Quality Needs	Evaluation Procedure
The virtual worlds should approximate real world environments as much as possible.	Having a look at the demo programs.
There should be additional graphical feature like particle effects, explosions, fog, ...	

Questions

- What is the general feeling in the 3D Virtual World (is everything smooth, does it look fabulous, ...)
- What do the characters and buildings look like (are the textures rendered nice, ...)
- Are there special effects and do they make the world even more astonishing?

Functionality

Definition. The capability of the software product to provide an appropriate set of functions for specified tasks and user objectives.

The functionality was the main point of interest during our selection procedure as we were interested in a highly customizable 3D Virtual World. Therefore this Section was structured more granularly according to the different functional attributes we were interested in.

Exporters

Quality Needs	Evaluation Procedure
Since we most probably want to create 3D Worlds in other programs, like Max or Maya, the 3D Virtual Worlds should provide exporters for 3D modeling programs.	Trying to export a hand modeled 3D scene.

Questions

- Are there exporter functionalities from at least one major 3D modeling application (3ds Max, Maya or Milkshape)?
- Is there a broad range of exporter options?
- What is the quality of the exporter documentation?
- Is it easy and comfortable to use the exporter?
- Does the exporter work as expected?
- Are the error messages meaningful?

Messaging

Quality Needs	Evaluation Procedure
There must be some sort of messaging system, so that agents can communicate with each other.	Writing a demo which expresses this functionality.

Questions

- Are there non trivial[1] messaging mechanisms?
- Is there a documentation or demo for this feature?
- What is this documentation like?
- Is the messaging system easy to use?

Scripting System

Quality Needs	Evaluation Procedure
The 3D Virtual Worlds should provide scripting languages to facilitate the development.	Trying to use the scripting system and exploring its possibilities.

[1]Since all the tested systems are based upon the object oriented paradigm, they all include interaction mechanisms between objects (function calls). We are interested in more elaborate messaging systems.

Questions

- Does the product provide a scripting system?
- Is there a documentation of this system?
- Are there tutorials or demo programs?
- What is this documentation like?
- What is the scripting language like (in terms of expressiveness, ease of use, ...)?
- What is the scripting system like[2] (in terms of structure, ease of use, ...)?

Network capabilities

Quality Needs	Evaluation Procedure
It should be possible to execute multiple instances of the 3D Virtual World client on different computers (i.e. there should be networking functionalities).	Reading the manuals, trying to incorporate the feature.

Questions

- Does the product provide network functionalities?
- Is there a documentation of this feature?
- Are there tutorials or demo programs?
- What is this documentation like?
- Is the networking system easy to use?
- Is the networking system powerful (in terms of provided functions, different networking structures, ...)?

[2]Note that we are speaking of the scripting language and the scripting system as two different terms. When we refer to the scripting language we mean the language and how things can be expressed with this language. When we speak of the scripting system, we mean the system behind the language and how this system has to be set up for correct use.

Java Bindings

Quality Needs	Evaluation Procedure
Since EIDE is implemented in Java it would be nice to have Java API support.	Reading the documentation.

Questions

- Are there Java bindings or wrapper classes?
- Is there also a documentation, tutorials or demos?
- What are these documents like?
- Are the bindings easy to setup and use?

Web Browser Plugins

Quality Needs	Evaluation Procedure
It would be advantageous to have some sort of 3D Web plugins, since the Web would be a great platform for executing the application.	Checking the options and trying to use them.

Questions

- Is it possible to embed created applications in web pages?
- Is there an explanation on how this can be achieved?
- Is it easy to embed the application?

APPENDIX C

The Tasks in the Scenario

Task 1

Type: Information Task
Description: The first task is to find out some information about yourself. What your interests are, where you are from and what actually your full name is.
How to solve: The user has to locate the "Profile" button on the user interface, navigate through the profile and find the name entry.
Q: What is your full name? **A:** Susan Miller

Task 2

Type: Movement Task
Description: You will find some additional background information on your travel plans in the forum. So, the next task is to go inside the forum building.
How to solve: The user has to go inside the forum building

Task 3

Type: Action Task
Description: Now open the Forum.
How to solve: The user has to locate the "Forum" button on the user interface (the button appeared when she entered the forum building) and click it.

Task 4

Type: Information Task	
Description: You have posted a message thread under the "Lounge" topic some time ago. Locate the message thread and read it to find out more about your travel plans.	
How to solve: The user has to navigate in the forum, find the respective message thread, read it and answer the questions.	
Q: Who is your travel companion? **A:** Elaine	
Q: To which city are you traveling first? **A:** Prague	
Q: Who is paying for the hotel rooms? **A:** Elaine	

Task 5

Type: Information Task	
Description: Elaine is logged in in Itchy Feet as well. Use the chat to find out where Elaine is standing	
How to solve: The user has to open the chat, contact Elaine and get the required information by talking to her.	
Q: Where is Elaine? **A:** Behind the auction house	

Task 6

Type: Movement Task	
Description: Now go to Elaine's avatar	
How to solve: The user has to go to Elaine's avatar which is standing behind the auction house (this information has been given in the chat conversation of the previous task)	

Task 7

Type: Information Task	
Description: In order to be able to pay with Elaine's credit card, you need to find out some personal information of Elaine. Find out Elaine's last name and her birthdate - because, coincidentally, Elaine's credit card expires exactly 30 years after she was born.	
How to solve: The user has to find out how the profile of Elaine can be viewed. This is achieved by performing a right click on Elaine's avatar which opens up a context menu from which the profile has to be selected. Then the respective information has to be located in the profile	
Q: What is Elaine's last name? **A:** Jordan	
Q: In which year does the credit card expire? **A:** 2012	
Q: In which month does the credit card expire? **A:** July	

Task 8

Type: Movement Task
Description: Now you still need the credit card number and the name of the credit card company to be able to purchase the hotel rooms. Elaine has left a clue in the St. Charles's Church, so, your next task is to go inside the St. Charles's Church.
How to solve: The user has to go inside the St. Charles's Church.

Task 9

Type: Information Task
Description: The required information is hidden somewhere in this room. Try to find it.
How to solve: This information has been written on the walls inside the St. Charles's Church. The user has to walk around in the St. Charles's Church and find it.
Q: What is Elaine's credit card number? **A:** 4391
Q: Which company issued the credit card? **A:** Visa

Task 10

Type: Movement Task
Description: Well done, now you are ready to book the hotel rooms. A travel agent is waiting for you in the travel agency to help you in choosing a nice hotel. Go inside the sale room number 1 in the travel agency building.
How to solve: The user has to go inside the sale room number 1 in the travel agency.

Task 11

Type: Information Task
Description: Use the private chat function to get some advice on good hotel offers from the travel agent. Find out which hotel you should book in which city.
How to solve: The user has to open the private chat by clicking on the "Private Chat" button that appeared on the interface as soon as she entered the sale room. Then she has to chat with the Employee to get the required information.
Q: What is the name of the recommended hotel in Prague? **A:** Hotel Jalta
Q: What is the name of the recommended hotel in Berlin? **A:** Berlin Mark Hotel

Task 12

Type: Action Task	
Description: You will have to book the hotel in Prague for a fixed price in the travel agency. Go back to the main room, search for a 2 Bed room in Prague from August 17th 2009 to August 20th 2009 and reserve it.	
How to solve: The user has to go back to the main room, locate the "Hotel Search" button on the user interface, click it and complete the wizard.	

Task 13

Type: Action Task	
Description: The hotel room reservation has been placed in your shopping cart. You can review it by clicking on the shopping cart button on the right side. Your next task is to pay the hotel room. Go to the cash desk and pay the hotel room with Elaine's credit card information.	
How to solve: The user has to go next to the cash desk, click on the "Pay" button and follow the payment wizard. The credit card information of Elaine that has been gathered in the previous task has to be entered.	

Task 14

Type: Movement Task	
Description: You will need to purchase the hotel room for Berlin in an auction. Go inside the auction house.	
How to solve: The user has to go inside the auction house.	

Task 15

Type: Movement Task	
Description: Find out where the next upcoming auction is taking place and go inside the auction room before the start of the auction.	
How to solve: The user can either directly walk into one of the auction rooms or click on the "Auctions" button to view a list of the upcoming auctions and then walk into an auction room.	

Task 16

Type: Action Task	
Description: The auction is going to start shortly. Use the auction interface to place bids in the auction. Try to purchase the hotel room as cheap as possible, but don't go any higher than 300 Euros.	
How to solve: The user has to click on the "Auction Interface" button on the user interface and use the interface to purchase the product.	

Task 17

Type: Movement Task
Description: The hotel room can now be found in the shopping cart. In the auction house, products are paid in the clearing room. Go inside the clearing room.
How to solve: The user has to go inside the clearing room within the auction house.

Task 18

Type: Action Task
Description: Again, pay the hotel room with Elaine's credit card information.
How to solve: The user has to click on the "Pay" button on the user interface and follow the payment wizard. This time the credit card information has already been filled out.

APPENDIX D

The Tasks in the Learning Area

Task 1

Type: Movement Task
Description: This is the task interface, you will use this interface throughout the evaluation to track and review your tasks. The task interface can be launched at any time by clicking on the "Task Interface" button in the right corner or by pressing "F1". The task interface is launched automatically when you successfully complete a movement or action task. In general there are three types of tasks: movement tasks, information tasks and action tasks. In a movement task you have to go to a specific area or to a specific room in a building. In an information task you have to find out a certain piece of information and in an action task you have to complete an interaction with the user interface. Let's start with a first movement task. The movement is controlled via the "WASD" keys. To move forward press "W", to move backwards press "S", to move left press "A" and to move right press "D". If in your evaluation session, the mouse is used to control the view, the "TAB" key is used to toggle the mouse cursor on and off. The task is started by clicking on the "Start Task" button below. This will close the task interface and you are ready to work on the task. Can you see the platform with the two stair cases in front of you? Go up the stairs onto the platform.
How to solve: The user has to walk onto the platform.

Task 2

Type: Action Task
Description: Very good! you finished the first task. The next task is an action task. In an action task you have to perform an operation on the graphical user interface. Let's try this out with the notepad. The notepad is a handy utility where you can write down notes that might be useful later in the evaluation. This will be necessary for information that you gather in information tasks. Now, your task is to open the notepad.
How to solve: The user has to open the notepad by clicking on the notepad button on the left side of the user interface.

Task 3

Type: Movement Task
Description: You finished another task. Your task progress is displayed by the progress bar above. It shows how many tasks you have already completed and how many are still left. You have already completed two of the four tasks in the experimentation area. Let's try a more complicated movement task. Go to the building, locate the entrance door and enter the building. A door is opened by pressing the "e" key when you are standing in front of the door.
How to solve: The user has to enter the building.

Task 4

Type: Information Task
Description: Now there is only one task left. The final task is an information task. As you can see the task interface has changed. A question and input box have appeared below. In an information task you have to answer all the questions by entering the correct answer in the input box below each question. In this task you have to find out who has written his name on the wall of the building.
How to solve: The user has to go around the building and find the writing on the wall.
Q: Who has written his name on the wall of the building? **A:** Helmut

APPENDIX E

The Code System

The code system that emerged during the analysis of the interview data from the evaluation is illustrated in Figure E.1. The code system is grouped according to four main categories: 3D games, 3D Virtual World, travel behavior and Itchy Feet. The first three categories capture the background and personal information of the test subjects, while the Itchy Feet category captures all information that is relevant to the Itchy Feet environment. The substructure of this category therefore exhibits a high granularity and includes the greatest number of codes.

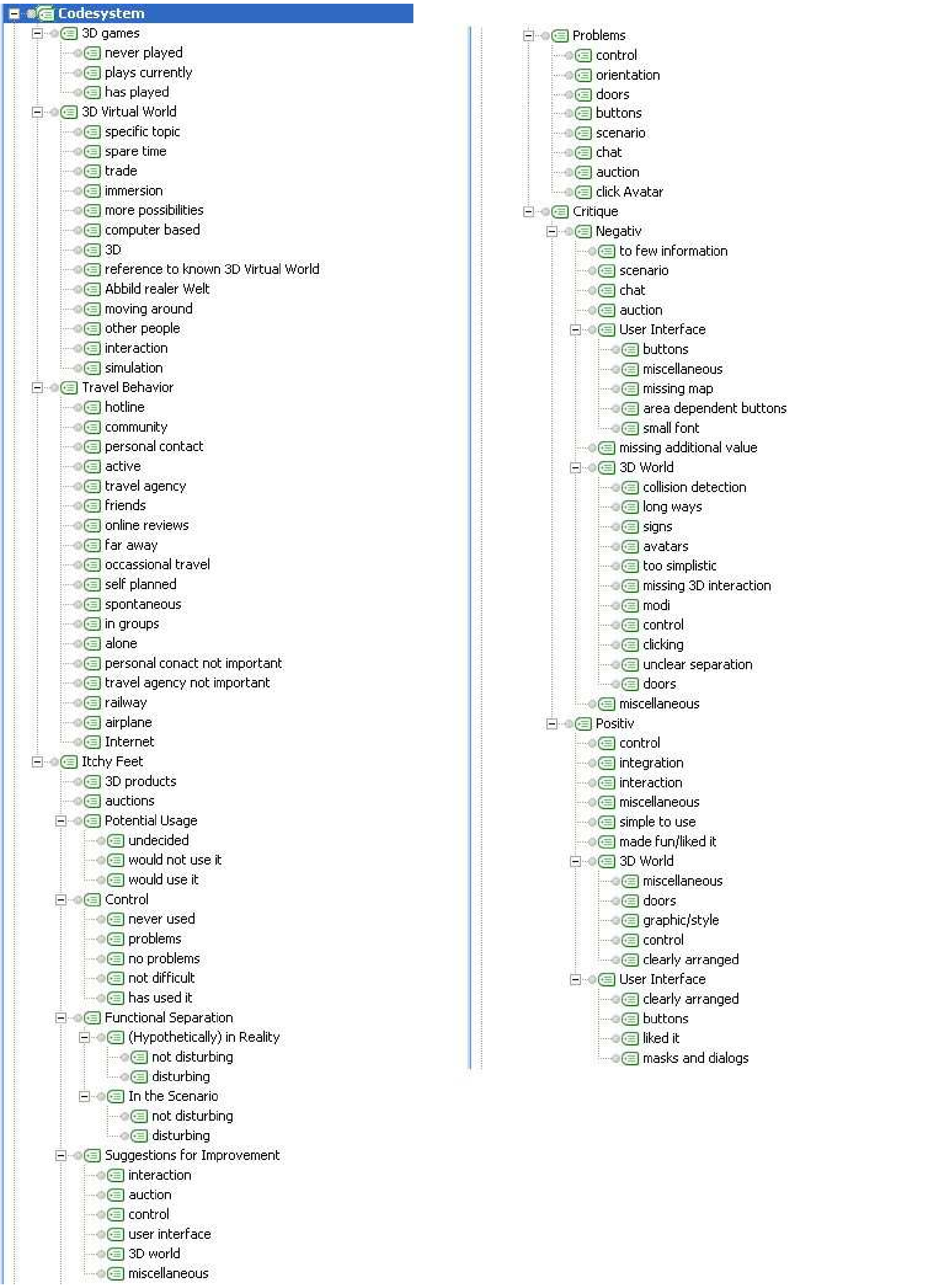

Figure E.1: The code system that emerged during analysis.

Bibliography

Adamo-Villani, N. and Wright, K. (2007). SMILE: An immersive learning game for deaf and hearing children, *Proceedings of the ACM SIGGRAPH 2007 educators program (SIGGRAPH '07)*, ACM, New York, NY, USA, p. 17.

Adobbati, R., Marshall, A. N., Scholer, A., Tejada, S., Kaminka, G., Schaffer, S. and Sollitto, C. (2002). Gamebots: A 3d virtual world test-bed for multi-agent team research, *Communications of the ACM* 45(1): 43–45.

Ambler, S. W. (2005). The agile unified process (AUP). `http://www.ambysoft.com/unifiedprocess/agileUP.html` (last accessed 27.03.2010).

Ambler, S. W. (2006). Unified - and agile. `http://www.drdobbs.com/architecture-and-design/184415460` (last accessed 27.03.2010).

Appelo, J. (2008). We increment to adapt, we iterate to improve, *Methods and Tools* 16(2): 9–22.

Arcos, J. L., Esteva, M., Noriega, P., Rodríguez-Aguilar, J. A. and Sierra, C. (2005). *Software Agent based Applications, Platforms and Development Kits*, Whitestein Series in Software Agent Technologies and Autonomic Computing, Birkhäuser Verlag, Basel, Switzerland, chapter An Integrated Development Environment for Electronic Institutions, pp. 121–142.

Arthur, K. W., Booth, K. S. and Ware, C. (1993). Evaluating 3d task performance for fish tank virtual worlds, *ACM Transactions on Information Systems* 11(3): 239–265.

Aschoff, F.-R. and Schwabe, G. (2009). On the evolution of online tourism communities - network battle or longtail niches?, *Proceedings of the 17th European Conference on Information Systems (ECIS '09)*, Verona, Italy, June 2009. Online Proceedings, paper available at `http://www.ecis2009.it/papers/ecis2009-0728.pdf` (last accessed 10.05.2010).

Bainbridge, W. S. (2007). The scientific research potential of virtual worlds, *Science* 317(5837): 472–476.

Balduino, R. (2007). Introduction to OpenUP (open unified process). `http://www.eclipse.org/epf/general/OpenUP.pdf` (last accessed 27.03.2010).

Barilleaux, J. (2001). *3D User Interfaces with Java 3D*, Manning Publications, Greenwich, CT, USA.

Baumgartner, M. (2008). *Real-world business in synthetic worlds: World characteristics and their relevance for commercial activities*, Master's thesis, Vienna University of Economics and Business, Vienna, Austria.

Beck, K. (2000). *Extreme Programming Explained: Embrace Change*, Addison-Wesley, Boston, MA, USA.

Berger, H., Dittenbach, M. and Merkl, D. (2004). User-oriented evaluation of a natural language tourism information system, *Information Technology and Tourism* 6(3): 167–180.

Berger, H., Dittenbach, M., Merkl, D., Bogdanovych, A., Simoff, S. and Sierra, C. (2006). Playing the e-business game in 3d virtual worlds, *Proceedings of the 18th Australian Conference on Computer-Human Interaction (OZCHI '06)*, ACM, New York, NY, USA, pp. 333–336.

Berger, H., Dittenbach, M., Merkl, D., Bogdanovych, A., Simoff, S. and Sierra, C. (2007). Opening new dimensions for e-tourism, *Virtual Reality* 11(2): 75–87.

Blade, R. A. and Padgett, M. L. (2002). *Handbook of Virtual Environments: Design, Implementation and Applications*, Lawrence Erlbaum Associates, Mahwah, NJ, USA, chapter Virtual Environments Standards and Terminology, pp. 15–28.

Boehm, B. W. (1986). A spiral model of software development and enhancement, *SIGSOFT Software Engineering Notes* 11(4): 14–24.

Bogdanovych, A. (2007). *Virtual Institutions*, PhD thesis, University of Technology Sydney, Syndey, Australia.

Bogdanovych, A., Berger, H., Sierra, C. and Simoff, S. (2005a). Humans and agents in 3d electronic institutions, *Proceedings of the 4th International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS '05)*, ACM, New York, NY, USA, pp. 1093–1094.

Bogdanovych, A., Berger, H., Simoff, S. J. and Sierra, C. (2005b). Narrowing the gap between humans and agents in e-commerce: 3d electronic institutions, *Proceedings of the 6th International Conference on Electronic Commerce and Web Technologies (EC-Web '05)*, Springer-Verlag, Berlin, Germany, pp. 128–137.

Bogdanovych, A., Berger, H., Simoff, S. J. and Sierra, C. (2006). Travel agents vs. online booking: Tackling the shortcomings of nowadays online tourism portals, *Proceedings of the 13th International Conference on Information Technologies in Tourism (ENTER' 06)*, Springer-Verlag, Vienna, Austria, pp. 418–428.

Bogdanovych, A. and Drago, S. (2006). Euclidean representation of 3d electronic institutions: Automatic generation, *Proceedings of the 8th International Working Conference on Advanced Visual Interfaces (AVI '06)*, ACM, New York, NY, USA, pp. 449–452.

Bogdanovych, A., Esteva, M., Simoff, S., Sierra, C. and Berger, H. (2007). A methodology for 3d electronic institutions, *Proceedings of the 6th International Conference on Autonomous Agents and Multiagent Systems (AAMAS '07)*, ACM, New York, NY, USA, pp. 1–3.

Bogdanovych, A., Rodríguez-Aguilar, J. A., Simoff, S. and Cohen, A. (2009a). Virtual agents and 3d virtual worlds for preserving and simulating cultures, *Proceedings of the 9th International Conference on Intelligent Virtual Agents (IVA '09)*, Springer-Verlag, Berlin, Germany, pp. 257–271.

Bogdanovych, A., Simoff, S. and Esteva, M. (2009b). Virtual institutions prototype, *Proceedings of the 8th International Conference on Autonomous Agents and Multiagent Systems (AAMAS '09)*, International Foundation for Autonomous Agents and Multiagent Systems, Richland, SC, USA, pp. 1373–1374.

Bowman, D. A., Gabbard, J. L. and Hix, D. (2002). A survey of usability evaluation in virtual environments: Classification and comparison of methods, *Presence: Teleoperators and Virtual Environments* 11(4): 404–424.

Bowman, D. A., Kruijff, E., LaViola, J. J. and Poupyrev, I. (2004). *3D User Interfaces: Theory and Practice*, Addison-Wesley, Boston, MA, USA.

Buhalis, D. and Law, R. (2008). Progress in information technology and tourism management: 20 years on and 10 years after the Internet – the state of etourism research, *Tourism Management* 29(4): 609–623.

Castronova, E. (2001). Virtual worlds: A first-hand account of market and society on the cyberian frontier, *The Gruter Institute Working Papers on Law, Economics, and Evolutionary Biology* 2(1). Open Access Journal, paper available at `http://www.bepress.com/giwp/default/vol2/iss1/art1` (last accessed 14.05.2010).

Castronova, E. (2003). On virtual economies, *Game Studies* 3(2). Open Access Journal, paper available at `http://www.gamestudies.org/0302/castronova/` (last accessed 14.05.2010).

Castronova, E. (2005). *Synthetic Worlds: The Business and Culture of Online Games*, The University of Chicago Press, Chicago, IL, USA.

Castronova, E. (2006). A cost-benefit analysis of real-money trade in the products of synthetic economies, *Info* 8(6): 51–68.

Chao, D. L. (2001). Doom as an interface for process management, *Proceedings of the 2001 SIGCHI Conference on Human Factors in Computing Systems (CHI '01)*, ACM, New York, NY, USA, pp. 152–157.

Chesney, T., Chuah, S.-H. and Hoffmann, R. (2009). Virtual world experimentation: An exploratory study, *Journal of Economic Behavior & Organization* 72(1): 618–635.

Chittaro, L. and Burigat, S. (2004). 3d location-pointing as a navigation aid in virtual environments, *Proceedings of the 7th International Working Conference on Advanced Visual Interfaces (AVI 'O4)*, ACM, New York, NY, USA, pp. 267–274.

Chiu, D. K. W. and Leung, H.-f. (2005). Towards ubiquitous tourist service coordination and integration: A multi-agent and semantic web approach, *Proceedings of the 7th International Conference on Electronic Commerce (ICEC '05)*, ACM, New York, NY, USA, pp. 574–581.

Cole, H. and Griffiths, M. D. (2007). Social interactions in massively multiplayer online role-playing gamers, *CyberPsychology & Behavior* 10(4): 575–583.

Coleman, G. and Verbruggen, R. (1998). A quality software process for rapid application development, *Software Quality Control* 7(2): 107–122.

Colombo, R. and Guerra, A. (2002). The evaluation method for software product, *Paper presented at the 15th International Conference on Software & Systems Engineering and their Applications (ICSSEA '02)*, Paris, France, December 2002.

Cruz-Neira, C., Sandin, D. J. and DeFanti, T. A. (1993). Surround-screen projection-based virtual reality: The design and implementation of the CAVE, *Proceedings of the 20th Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH '93)*, ACM, New York, NY, USA, pp. 135–142.

Cyr, D., Hassanein, K., Head, M. and Ivanov, A. (2007). The role of social presence in establishing loyalty in e-service environments, *Interacting with Computers* 19(1): 43–56.

Dang, N.-T., Chatelain, C., Pergandi, J.-M. and Mestre, D. (2008). A framework for design and evaluation of collaborative virtual environments, *Proceedings of the 3ème Journées de l'Association Francaise de Réalité Virtuelle*, Bordeaux, France, October 2008. Online Proceedings, paper available at `https://pedagogie.ec-nantes.fr/afrv/uploads/file/afrv08/5.pdf` (last accessed 14.05.2010).

de Freitas, S. (2009). Serious virtual worlds a scoping study. `http://www.jisc.ac.uk/media/documents/publications/seriousvirtualworldsv1.pdf` (last accessed 15.01.2010).

Debenham, J. and Simoff, S. (2006). An e-market framework for informed trading, *Proceedings of the 15th International Conference on World Wide Web (WWW '06)*, ACM, New York, NY, USA, pp. 651–658.

Debenham, J. and Simoff, S. (2009). Believable electronic trading environments on the Web, *Proceedings of the 2009 IEEE/WIC/ACM International Conference on Web Intelligence (WI '09)*, IEEE Computer Society, Washington, DC, USA, pp. 631–638.

Dieterle, E. (2009). *Encyclopedia of Multimedia Technology and Networking (2nd ed)*, Information Science Reference, Hershey, PA, USA, chapter Multi-User Virtual Environments for Teaching and Learning, pp. 1033–1041.

Dignum, V. and Dignum, F. (2001). Modelling agent societies: Co-ordination frameworks and institutions, *Proceedings of the 10th Portuguese Conference on Artificial Intelligence (EPIA '01)*, Springer-Verlag, Berlin, Germany, pp. 191–204.

Dignum, V., Weigand, H. and Xu, L. (2002). Agent societies: Towards frameworks-based design, *Proceedings of the 2nd International Workshop on Agent-Oriented Software Engineering (AOSE '01)*, Springer-Verlag, London, UK, pp. 33–49.

Dippelreiter, B., Grün, C., Pöttler, M., Seidel, I., Berger, H., Dittenbach, M. and Pesenhofer, A. (2008). Online tourism communities on the path to Web 2.0: An evaluation, *Information Technology & Tourism* 10(4): 329–353.

Drettakis, G., Roussou, M., Reche, A. and Tsingos, N. (2007). Design and evaluation of a real-world virtual environment for architecture and urban planning, *Presence: Teleoperators and Virtual Environments* 16(3): 318–332.

Esteva, M., de la Cruz, D. and Sierra, C. (2002). ISLANDER: An electronic institutions editor, *Proceedings of the 1st International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS '02)*, ACM, New York, NY, USA, pp. 1045–1052.

Esteva, M., Rodríguez-Aguilar, J. A., Sierra, C., Garcia, P. and Arcos, J. L. (2001). *Agent Mediated Electronic Commerce*, Vol. 1991 of *Lecture Notes in Computer Science*, Springer-Verlag, Berlin, Germany, chapter On the Formal Specifications of Electronic Institutions, pp. 126–147.

Esteva, M., Rosell, B., Rodríguez-Aguilar, J. A. and Arcos, J. L. (2004). Ameli: An agent-based middleware for electronic institutions, *Proceedings of the 3rd International Joint Conference on Autonomous Agents and Multi Agent Systems (AAMAS '04)*, IEEE Computer Society, Washington, DC, USA, pp. 236–243.

Fencott, C. (2004). *Developing Future Interactive Systems*, Idea Group, Hershey, PA, USA, chapter A Methodology of Design for Virtual Environments, pp. 66–91.

Finin, T., Fritzson, R., McKay, D. and McEntire, R. (1994). KQML as an agent communication language, *Proceedings of the 3rd International Conference on Information and Knowledge Management (CIKM '94)*, ACM, New York, NY, USA, pp. 456–463.

Fowler, M. and Highsmith, J. (2001). The agile manifesto. `http://agilemanifesto.org/` (last accessed 14.05.2010).

Froschauer, J., Seidel, I., Gärtner, M., Berger, H. and Merkl, D. (2009). New directions in science communication: A virtual research & experience landscape, *Proceedings of the World Conference on E-Learning in Corporate, Government, Healthcare, & Higher Education (E-Learn '09)*, AACE, Vancouver, Canada, pp. 2590–2597.

Froschauer, J., Seidel, I., Gärtner, M., Berger, H. and Merkl, D. (2010). Design and evaluation of a serious game for immersive cultural training, *16th International Conference on Virtual Systems and Multimedia (VSMM '10).* submitted for publication.

Gabbard, J. L. and Hix, D. (1997). A taxonomy of usability characteristics in virtual environments, *Technical report*, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA.

Gabbard, J. L., Hix, D. and Swan, J. E. (1999). User-centered design and evaluation of virtual environments, *IEEE Computer Graphics & Applications* 19(6): 51–59.

Gartner Inc. (2007). Gartner says 80 percent of active Internet users will have a "second life" in the virtual world by the end of 2011. `http://www.gartner.com/it/page.jsp?id=503861` (last accessed 02.05.2010).

Gärtner, M., Seidel, I. and Berger, H. (2008). Agent mediated trading in a 3d e-tourism environment, *Proceedings of the 10th International Conference on Electronic Commerce (ICEC '08)*, ACM, New York, NY, USA, pp. 1–10.

Gärtner, M., Seidel, I., Froschauer, J. and Berger, H. (2010). The formation of virtual organizations by means of electronic institutions in a 3d e-tourism environment, *Information Sciences, Special Issue: Virtual Agent and Organization Modeling: Theory and Applications* . in press.

Gilb, T. (1985). Evolutionary delivery versus the "waterfall model", *SIGSOFT Software Engineering Notes* 10(3): 49–61.

Glenday, C. (ed.) (2009). *Guinness World Records 2009*, Bantam Bell, New York, NY, USA.

González-Calleros, J. M., Vanderdonckt, J. and Muñoz Arteaga, J. (2009). A structured approach to support 3d user interface development, *Proceedings of the 2nd International Conference on Advances in Computer-Human Interactions (ACHI '09)*, IEEE Computer Society, Washington, DC, USA, pp. 75–81.

Gratzer, M., Werthner, H. and Winiwarter, W. (2004). Electronic business in tourism, *International Journal of Electronic Business* 2(5): 450–459.

Griffiths, M. D., Davies, M. N. O. and Chappell, D. (2003). Breaking the stereotype: The case of online gaming, *CyberPsychology & Behavior* 6(1): 81–91.

Hassanein, K. and Head, M. (2007). Manipulating perceived social presence through the Web interface and its impact on attitude towards online shopping, *International Journal of Human-Computer Studies* 65(8): 689–708.

Hevner, A. R., March, S. T., Park, J. and Ram, S. (2004). Design science in information systems research, *MIS Quarterly* 28(1): 75–106.

Hix, D. and Gabbard, J. L. (2002). *Handbook of Virtual Environments: Design, Implementation and Applications*, Lawrence Erlbaum Associates, Mahwah, NJ, USA, chapter Usability Engineering of Virtual Environments, pp. 681–699.

Hix, D., Swan, II, J. E., Gabbard, J. L., McGee, M., Durbin, J. and King, T. (1999). User-centered design and evaluation of a real-time battlefield visualization virtual environment, *Proceedings of the 1999 IEEE Conference on Virtual Reality (VR '99)*, IEEE Computer Society, Washington, DC, USA, pp. 96–103.

IEEE Computer Society (1991). IEEE Std. 1074–1991, Standard for developing software life cycle processes.

International Organization for Standardization (ISO) (2003). ISO/IEC 9126:2003 Software engineering – product quality.

Jäkälä, M. and Pekkola, S. (2007). From technology engineering to social engineering: 15 years of research on virtual worlds, *SIGMIS Database* 38(4): 11–16.

Kopper, R., Ni, T., Bowman, D. A. and Pinho, M. (2006). Design and evaluation of navigation techniques for multiscale virtual environments, *Proceedings of the 2006 IEEE Conference on Virtual Reality (VR '06)*, IEEE Computer Society, Washington, DC, USA, pp. 175–182.

Kot, B., Wünsche, B., Grundy, J. and Hosking, J. (2005). Information visualisation utilising 3d computer game engines case study: A source code comprehension tool, *Proceedings of the 6th ACM SIGCHI New Zealand Chapter's International Conference on Computer-Human Interaction (CHINZ '05)*, ACM, New York, NY, USA, pp. 53–60.

Krishna, V. (2010). *Auction Theory*, Academic Press, Amsterdam, The Netherlands.

Kroll, P. and MacIsaac, B. (2006). *Agility and Discipline Made Easy: Practices from OpenUP and RUP*, Addison-Wesley, Upper Saddle River, NJ, USA.

Kruchten, P. (2006). *The Rational Unified Process: An Introduction*, Addison-Wesley, Upper Saddle River, NJ, USA.

Kruchten, P. (2007). Voyage in the agile memeplex, *Queue* 5(5): 38–44.

Krüger, W. and Fröhlich, B. (1994). The responsive workbench, *IEEE Computer Graphics & Applications* 14(3): 12–15.

Kuckartz, U., Dresing, T., Rädiker, S. and Stefer, C. (2008). *Qualitative Evaluation - Der Einstieg in die Praxis*, VS Verlag für Sozialwissenschaften, Wiesbaden, Germany.

Larman, C. and Basili, V. R. (2003). Iterative and incremental development: A brief history, *Computer* 36(6): 47–56.

Lastowka, G. and Hunter, D. (2004). The laws of the virtual worlds, *California Law Review* 92(1): 1–73.

Livatino, S. and Koeffel, C. (2008). *Advances in Human Computer Interaction*, II-TECH Education and Publishing, Vienna, Austria, chapter Simple Guidelines for Testing VR Applications, pp. 289–310.

Lofland, J. and Lofland, L. H. (1995). *Analyzing social settings*, Wadsworth, Belmont, CA, USA.

Lowood, H. (2009). Memento mundi: Are virtual worlds history?, *Proceedings of the 6th International Conference on Preservation of Digital Objects (iPRES '09)*, University of California, Oakland, CA, USA, pp. 121–128.

Maes, P. and Nardi, D. (1988). *Meta-level Architectures and Reflection*, North-Holland, Amsterdam, The Netherlands.

Malaby, T. (2006). Parlaying value capital in and beyond virtual worlds, *Games and Culture* 1(2): 141–162.

Manojlovich, J., Prasithsangaree, P., Hughes, S., Chen, J. and Lewis, M. (2003). UT-SAF: A multiagent-based framework for supporting military-based distributed interactive simulations in 3d virtual environments, *Proceedings of the 35th Conference on Winter Simulation (WSC '03)*, Winter Simulation Conference, New Orleans, LA, USA, pp. 960–968.

Martin, C., Schreckenghost, D., Bonasso, P., Kortenkamp, D., Milam, T. and Thronesbery, C. (2003). An environment for distributed collaboration among humans and software agents, *Proceedings of the 2nd International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS '03)*, ACM, New York, NY, USA, pp. 1062–1063.

McConnell, S. (1997). *Rapid Development: Taming Wild Software Schedules*, Microsoft Press, Redmond, WA, USA.

Menchaca, R., Balladares, L., Quintero, R. and Carreto, C. (2005). Software engineering, HCI techniques and Java technologies joined to develop Web-based 3d-collaborative virtual environments, *Proceedings of the 2nd Latin American Conference on Human-Computer Interaction (CLIHC '05)*, ACM, New York, NY, USA, pp. 40–51.

Modjeska, D. and Waterworth, J. (2000). Effects of desktop 3d world design on user navigation and search performance, *Proceedings of the 4th International Conference on Information Visualization (IV '00)*, IEEE Computer Society, Washington, DC, USA, pp. 215–220.

Molina, J. P., García, A. S., López-Jaquero, V. and González, P. (2005). Developing VR applications: The TRES-D methodology, *Proceedings of the 1st International Workshop on Methods & Tools for Designing VR Applications (MeTo-VR '05)*, Ghent, Belgium, October 2005. CD-ROM Proceedings, paper available at `http://wise.vub.ac.be/MeToVR/downloads/Paper3_Molina_garcia.pdf` (last accessed 14.05.2010).

Molina, J. P., González, P., Lozano, M. D., Montero, F. and López-Jaquero, V. (2003). Bridging the gap: Developing 2d and 3d user interfaces with the ideas methodology, *Proceedings of the 10th Workshop on the Design, Specification and Verification of Interactive Systems*, Springer-Verlag, Berlin, Germany, pp. 303–315.

Moloney, J., Amor, R., Furness, J. and Moores, B. (2003). Design critique inside a multi-player game engine, *Proceedings of the 20th CIB W78 Conference on Information Technology in Construction*, CIB, Rotterdam, The Netherlands, pp. 255–262.

Nakanishi, H. and Ishida, T. (2004). Freewalk/Q: Social interaction platform in virtual space, *In Proceedings of the 11th ACM Symposium on Virtual Reality Software and Technology (VRST '04)*, ACM, New York, NY, USA, pp. 97–104.

Nielsen, J. (1993). *Usability Engineering*, Academic Press, San Diego, CA, USA.

O'Reilly, T. (2005). What is Web 2.0. `http://oreilly.com/web2/archive/what-is-web-20.html` (last accessed 13.01.2010).

Palmer, S. R. and Felsing, J. M. (2002). *A Practical Guide to Feature-Driven Development*, Prentice Hall, Upper Saddle River, NJ, USA.

Pastoor, S. and Wöpking, M. (1997). 3-d displays: A review of current technologies, *Displays* 17(2): 100–110.

Payne, T. R., Sycara, K. and Lewis, M. (2000). Varying the user interaction within multi-agent systems, *Proceedings of the 4th International Conference on Autonomous Agents (AGENTS '00)*, ACM, New York, NY, USA, pp. 412–418.

Punter, T. (1997). Using checklists to evaluate software product quality, *Proceedings of the 8th European Software Control and Metrics Conference (ESCOM '97)*, The ESCOM Conference, Reading, UK, pp. 143–150.

Rising, L. and Janoff, N. S. (2000). The scrum software development process for small teams, *IEEE Software* 17: 26–32.

Robles, A., Molina, J. P., López-Jaquero, V. and García, A. S. (2005). Even better than reality: The development of a 3-d online store that adapts to every user and every platform, *Proceedings of the 11th International Conference on Human-Computer Interaction (HCI '05)*, Las Vegas, NV, USA, July 2005. CD-ROM Proceedings.

Rodriguez, I., Puig, A., Esteva, M., Sierra, C., Bogdanovych, A. and Simoff, S. (2008). Intelligent objects to facilitate human participation in virtual institutions, *Proceedings of the 2008 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT '08)*, IEEE Computer Society, Washington, DC, USA, pp. 196–199.

Royce, W. W. (1970). Managing the development of large software systems, *Proceedings of the Western Electronic Show and Convention (WesCon)*, IEEE Computer Society, Washington, DC, USA, pp. 1–9.

Sánchez-Segura, M.-I., de Amescua Seco, A. and Cuadrado, J.-J. (2003). Software engineering and HCI techniques joined to develop virtual environments, *Proceedings of the 1st Workshop on Bridging the Gaps Between Software Engineering and Human-Computer Interaction (SE-HCI '03)*, Portland, OR, USA, May 2003. Online Proceedings, paper available at `http://www.se-hci.org/bridging/icse/p20-25.pdf` (last accessed 14.05.2010).

Schwabe, G. and Prestipino, M. (2005). How tourism communities can change travel information quality, *Proceedings of the 13th European Conference on Information Systems, Information Systems in a Rapidly Changing Economy, (ECIS '05)*, Regensburg, Germany, May 2005. Online Proceedings, paper available at `http://is2.lse.ac.uk/asp/aspecis/20050147.pdf` (last accessed 14.05.2010).

Schwaber, K. (2004). *Agile Project Management with Scrum*, Microsoft Press, Redmond, WA, USA.

Seidel, I. (2008). Developing a 3d e-tourism environment, *Paper presented at the ENTER 2008 PhD Workshop*, Innsbruck, Austria, January 2008.

Seidel, I. and Berger, H. (2007). Integrating electronic institutions with 3d virtual worlds, *Proceedings of the 2007 IEEE/WIC/ACM International Conference on Intelligent Agent Technology (IAT '07)*, IEEE Computer Society, Washington, DC, USA, pp. 481–484.

Seidel, I., Gärtner, M., Froschauer, J., Berger, H. and Merkl, D. (2009a). An agent-based centralized e-marketplace in a virtual environment, *Proceedings of the 21st International Conference on Software Engineering and Knowledge Engineering (SEKE '09)*, Knowledge Systems Institute Graduate School, Skokie, IL, USA, pp. 218–221.

Seidel, I., Gärtner, M., Froschauer, J., Berger, H. and Merkl, D. (2010a). A qualitative evaluation of a 3d e-tourism environment, *International Journal of Human-Computer Studies* . submitted for publication.

Seidel, I., Gärtner, M., Froschauer, J., Berger, H. and Merkl, D. (2010b). Towards a holistic methodology for engineering 3d virtual world applications, *Proceedings of the International Conference on Information Society (i-Society '10).* accepted for publication.

Seidel, I., Gärtner, M., Pöttler, M., Berger, H., Dittenbach, M. and Merkl, D. (2009b). *Tourism Informatics: Visual Travel Recommender Systems, Social Communities, and User Interface Design*, Information Science Reference, Hershey, PA, USA, chapter Itchy Feet: A 3D e-Tourism Environment, pp. 209–242.

Shewhart, W. A. (1986). *Statistical Method from the Viewpoint of Quality Control*, Dover Publications, New York, NY, USA. (reprint from 1939).

Singer, M. J., Long, R., Stahl, J. and Kusumoto, L. (2008). Formative evaluation of a massively multi-player persistent (MMP) environment for asymmetric warfare exercises, *Technical report*, United States Army Research Institute for the Behavioral and Social Sciences, Arlington, VA, USA.

Sivan, Y. (2008). 3d + 3c = "real" virtual worlds, *Cutter IT Journal* 21(9): 6–13.

Smith, G., Maher, M. L. and Gero, J. S. (2003). Designing 3d virtual worlds as a society of agents, *Proceedings of the 10th International Conference on Computer Aided Architectural Design Futures (CAADFutures '03)*, Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 105–114.

Sousa Santos, B., Dias, P., Pimentel, A., Baggerman, J.-W., Ferreira, C., Silva, S. and Madeira, J. (2009). Head-mounted display versus desktop for 3d navigation in virtual reality: A user study, *Multimedia Tools Applications* 41(1): 161–181.

Stanney, K. M., Mollaghasemi, M., Reeves, L., Breaux, R. and Graeber, D. A. (2003). Usability engineering of virtual environments (VEs): Identifying multiple criteria that drive effective VE system design, *International Journal of Human-Computer Studies* 58(4): 447–481.

Stanney, K. M. and Zyda, M. (2002). *Handbook of Virtual Environments: Design, Implementation and Applications*, Lawrence Erlbaum Associates, Mahwah, NJ, USA, chapter Virtual Environments in the 21st Century, pp. 1–14.

Sutcliffe, A. and Gault, B. (2004). Heuristic evaluation of virtual reality applications, *Interacting with Computers* 16(4): 831–849.

Tan, D. S., Robertson, G. G. and Czerwinski, M. (2001). Exploring 3d navigation: Combining speed-coupled flying with orbiting, *Proceedings of the 2001 SIGCHI Conference on Human Factors in Computing Systems (CHI '01)*, ACM, New York, NY, USA, pp. 418–425.

Traum, D. and Rickel, J. (2002). Embodied agents for multi-party dialogue in immersive virtual worlds, *Proceedings of the 1st International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS '02)*, ACM, New York, NY, USA, pp. 766–773.

Trescak, T., Esteva, M. and Rodriguez, I. (2009). General shape grammar interpreter for intelligent designs generations, *Proceedings of the 6th International Conference on Computer Graphics, Imaging and Visualization (CGIV '09)*, IEEE Computer Society, Washington, DC, USA, pp. 235–240.

Trescak, T., Esteva, M. and Rodriguez, I. (2010). A virtual world grammar for automatic generation of virtual worlds, *Proceedings of the 29th Conference on Computer Graphics International (CGI '10)*. accepted for publication.

Tromp, J. G. (2001). *Systematic Usability Design and Evaluation for Collaborative Virtual Environments*, PhD thesis, University of Nottingham, Department of Manufacturing Engineering and Department of Computer Science, Nottingham, UK.

Tromp, J. G., Steed, A. and Wilson, J. R. (2003). Systematic usability evaluation and design issues for collaborative virtual environments, *Presence: Teleoperators and Virtual Environments* 12(3): 241–267.

Wang, Y., Yu, Q. and Fesenmaier, D. R. (2002). Defining the virtual tourist community: Implications for tourism marketing, *Tourism Management* 23(4): 407–417.

Werthner, H. and Klein, S. (1999). *Information Technology and Tourism - A Challenging Relationship*, Springer-Verlag, Vienna, Austria.

Wilson, J. R., Eastgate, R. M. and D'Cruz, M. (2002). *Handbook of Virtual Environments: Design, Implementation and Applications*, Lawrence Erlbaum Associates, Mahwah, NJ, USA, chapter Structured Development of Virtual Environments, pp. 353–378.

Woolridge, M. J. (2001). *An Introduction to Multiagent Systems*, John Wiley & Sons, New York, NY, USA.

Yee, N. (2006). The demographics, motivations, and derived experiences of users of massively multi-user online graphical environments, *Presence: Teleoperators and Virtual Environments* 15(3): 309–329.

Yeung, C., Pang-Fei, T. and Yen, J. (1998). A multi-agent based tourism kiosk on Internet, *Proceedings of the 31st Annual Hawaii International Conference on System Sciences-Volume 4 (HICSS '98)*, IEEE Computer Society, Washington, DC, USA, p. 452.

Zambonelli, F., Jennings, N. R. and Wooldridge, M. (2003). Developing multiagent systems: The Gaia methodology, *ACM Transactions on Software Engineering Methodologies* 12(3): 317–370.

Resume

Personal Information

Name:	Ingo Seidel
Address:	Wehlistrasse 159/17 1020 Vienna, Austria
Birthdate:	March, 2nd 1983
Birthplace:	Klagenfurt, Austria
Citizenship:	Austria

Education

May 2007 - present	PhD Studies in Technical Sciences at the Vienna University of Technology
March 2007	Master in Computer Science (MSc.)
Jan. 2005 - March 2007	Master Studies in Computational Intelligence at the Vienna University of Technology
January 2005	Bachelor in Computer Science (BSc.)
Sep. 2001 - Jan. 2005	Bachelor Studies in Software & Information Engineering at the Vienna University of Technology
1993 - 2001	Primary and Secondary School, in Viktring
1989 - 1993	Elementary School, in Klagenfurt

Professional Experience

May 2007 - present	PhD Student in the "Itchy Feet" Research Project funded by the Austrian Science Fund (FWF)
June 2007 - Aug. 2007	Research Assistant at the Purdue University as part of the Summer Undergraduate Research Fellowship (SURF)
April 2007	Freelancer at the Electronic Commerce Competence Center (EC3)
July 2006 - Aug. 2006	Internship at Oracle Austria in the Expert Services Group
February 2003	Development of a web based office equipment management system for the Chamber of Agriculture of Carinthia

Teaching Experience

Mar. 2005 - Jan. 2007	Tutor of the course Algorithms and Data Structures at the Institute of Computer Graphics and Algorithms at the Vienna University of Technology
Oct. 2004 - Jan. 2005	Tutor of the course Distributed Systems at the Institute of Information Systems at the Vienna University of Technology