Structuring Interactions in a Hybrid Virtual Environment:
Infrastructure & Usability

Keywords: Virtual Environments, Human-Agent interactions, Usability

Abstract: Humans in the Digital Age are continuously exploring different forms of socializing on-line. Social 3D Virtual Worlds provide an alternative that are gaining in popularity. They constitute virtual environments where people freely socialize by participating in open-ended activities. Moreover, Virtual Worlds can also be used to engage humans in e-* (e-government, e-learning, e-commerce) applications, the so called Serious Virtual Worlds. Implicitly, these serious applications have specific goals that require *structured environments* where participants play specific roles and perform activities by following well-defined protocols and norms. In this paper we advocate for the use of *Virtual Institutions* to provide explicit structure to current Social 3D Virtual Worlds. We refer to the resulting system as *hybrid* (participants can be both human and software agents) and *structured* Virtual Environment. Specifically, we present *v-mWater* (a water market, an e-government application deployed as a Virtual Institution), the infrastructure that supports participants' interactions, and the evaluation of its usability.

1 INTRODUCTION

Contemporary society has massively adopted different forms of socializing on-line. Social 3D Virtual Worlds (VW) are a relatively new form of doing it. They are persistent Virtual Environments (VE) where people experience others as being there with them, freely socializing in activities and events (Book, 2004). However, virtual worlds can also be used to engage humans in serious applications with reality-based thematic settings (e.g., e-government, e-learning and e-commerce), the so-called Serious VWs.

Social VWs are conceived as open-ended *unstructured environments* that lack of defined and controlled interactions, whereas Serious VWs can be seen as inherently *structured environments* where people play specific roles, and where some activities follow well-defined protocols and norms that fulfil specific goals. Although users in such structured (regulated) environments may feel over-controlled, with most of their interactions constrained, this can turn around and feel more guided and safe whenever regulations direct and coordinate their complex activities.

Current VWs platforms (e.g Second Life, OpenSim), mainly focused on providing participants with open-ended social experiences, do not explicitly consider the definition of structured interactions, neither contemplate their control at run-time.

Therefore, we advocate the use of *Virtual Institutions* (VI), which combine *Electronic Institutions* (EI) and VWs, to design *hybrid and structured Virtual Environments*. EIs provide an infrastructure to regulate participants' interactions. Specifically, an EI is an organisation centred Multi-Agent System (MAS) that structures agent interactions by establishing the sequence of actions agents are permitted/expected to perform (Esteva et al., 2004). VWs offer an intuitive interface to allow humans to be aware of MAS state as well as to participate in a seamless way. By *hybrid* we mean that participants can be both human and bots (i.e., software agents). They both perform complex interactions to achieve real-life goals (e.g., tax payment, attending a course, trading).

In this paper we present an example of a hybrid regulated scenario in an e-government application (*v-mWater*, a *v*irtual *m*arket based on trading *Water*), the infrastructure that supports participants' interactions in this scenario, and the evaluation of its usability. The *Virtual Institutions eXEcution Environment* (VIXEE) (xxx, 9999c) infrastructure enables the execution of a VI. As far as we know, there are no previous evaluations about the usability of an application deployed with a similar infrastructure (i.e. a strongly regulated and hybrid virtual environment). We are specially interested in analysing how users perceive their interaction with bots.

This paper is structured as follows. First, Section 2 presents related work. Second, Section 3 describes the model of our regulated scenario. Next, Section 4 presents the provided infrastructure focusing on human-agent interactions. Section 5 shows an example execution of *v-mWater*. Section 6 describes the usability test performed to evaluate our solution. Finally, Section 7 draws some conclusions and future work.

2 RELATED WORK

In this section we review prior research works on structured (regulated) interactions in Multi-User/Agent environments, infrastructures that extend basic functionalities of VW platforms, and usability evaluation of virtual environments.

Regulation has been subject of study both in multi-agent systems and human computer interaction fields. In the MAS field, several studies focused on agents societies and proposed methodologies and infrastructures to regulate and coordinate agents interactions (Dignum et al., 2002) (Esteva et al., 2004). Specifically, Cranefield et al. adapted a tool, originally developed for structuring social interactions between software agents, to model and track rules of social expectations in Second Life (SL) virtual world such as, for example, "no one should ever fly" (Cranefield and Li, 2009). They used temporal logic to implement the regulative system. In our case, we use Electronic Institutions (EI), a well known Organization Centered MAS (OCMAS), to regulate participants' interactions in hybrid 3D virtual environments.

Several HCI researches focused on regulation mechanisms for groupware applications, i.e CSCW (Computer Supported Collaborative Work). In general, these mechanisms define roles, activities and interaction methods for collaborative applications. One research work used social rules (and the conditions to execute them) to control the interactions among the members of a workgroup (Mezura-Godoy and Talbot, 2001). Another work proposed regulation mechanisms to address social aspects of collaborative work such as the location where the activity take place, collaborative activities by means of scenarios, and the participants themselves (Ferraris and Martel, 2000). At a conceptual level our regulation model based on EIs (i.e activities, protocols, roles) shares similarities with those applied for groupware applications.

Related to regulation of activities in virtual environments, Paredes et al. (Paredes and Martins, 2007) proposed the Social Theatres model. This model regulates social interactions in a VE based on the concept of *theatre* (i.e. a space where actors play roles and follow a well-defined interaction workflow regulated by a set of rules). In posterior works, they conducted a survey to evaluate user preferences about VE interfaces. This allowed to design a 3D interface based on the Social Theatres model and users' preferences (Guerra et al., 2008). Recently they have proposed a multi-layer software architecture implementing the Social Theatres model (Paredes and Martins, 2010). Although it has been designed to be adaptable, this architecture presents some limitations on the dynamic adaptation of rules. On the contrary, as long as our system uses an EI as regulation infrastructure, it inherits self-adaptation properties of EIs (xxx, 9999a). Another main difference between our system and the Social Theatres model is that the latter is a web-based environment (relying in web services) and our system is independent of the technology that implements the virtual environment.

Infrastructures or middlewares that extend basic functionalities of VW platforms mainly focus on incorporating both intelligent agent behaviors (connecting MAS to VWs platforms) and advanced visualizations in serious virtual worlds.

There is a variety of works that have connected multi-agent systems to VW platforms. It may be worth mentioning a work that integrated a MAS developed in JADE with the VW server Open Wonderland[1] by modifying an existing module that starts a JADE agent (Blair and Lin, 2011). Other works generalise this approach. CIGA (van Oijen et al., 2011) is a general purpose middleware framework where an in-house developed game engine can be connected to a MAS. It was tested with 2APL, Jadex and a custom MAS. Another middleware was proposed as a standard to connect MAS systems to environments (Behrens et al., 2011). They proposed a so called Environment Interface Standard (EIS) which supports several MAS platforms (2APL, GOAL, JADEX and Jason) and different environments (e.g. GUI applications or videogame worlds). The infrastructure that we present in this paper, regulates participants' interactions at run-time and provides the virtual space with intelligent behaviors.

There are also recent research works that have focused on extending, using plug-ings, VW platforms with advanced graphics for serious applications. As an example, a framework for Open Simulator creates scientific visualizations of biomechanical and neuromuscular data which allows to explore and analyse interactively such data (Pronost et al., 2011). In another work, Open Simulator is used as the real-time collaboration scenario by connecting a bio-molecular modelling application (Gajananan et al., 2010).

Regarding usability evaluation of virtual environments, Bowman et al. analyzed a list of issues such as the physical environment, the user, the evaluator and the type of usability evaluation, and proposed a

[1] http://openwonderland.org/

new classification space for evaluation approaches: sequential evaluation and testbed. Sequential evaluation, that includes heuristic, formative/exploratory and summative evaluations, is done in the context of a particular application and can have both qualitative and quantitative results. Testbed is done in a more generic evaluation context, and usually has quantitative results obtained through the creation of testbeds that involve all the important aspects of an interaction task (Bowman et al., 2002a) (Bowman et al., 1999). There are a number of researches that have proposed different evaluation frameworks for collaborative virtual environments (Tsiatsos et al., 2010) (Tromp et al., 2003). The approach that we have followed in this research paper is the sequential approach, mainly formative because we observe users interacting in our hybrid environment but also summative because we take some measures of time and errors performing tasks.

3 EXAMPLE OF A REGULATED SCENARIO

Our example scenario is a *v*irtual *m*arket based on trading *Water* (*v-mWater*). It is a simplification of m-Water (Giret et al., 2011) implemented as a VI which models an electronic market of water rights in the agriculture domain (xxx, 9999b).

3.1 Water market

In our market, participants negotiate water rights. In an agricultural context, a water right refers to the right of an irrigator to use water from a public water source (e.g., a river or a pond). It is associated to a farmland and the volume of its irrigation water is specified in cubic metre units (m^3). An *agreement* is the result of a negotiation where a seller settles with a buyer to reallocate (part of) the water from her/his water rights for a fixed period of time in exchange for a given amount of money.

We consider farmlands irrigating from controlled water sources within a hydrographic basin. At the beginning of the *irrigation season*, public authorities estimate the water reserves and assign a given quantity of water for each *water right*. *Tradable water rights* contain the surplus of water the irrigators expect to have on their *water rights* and decide to sell them[2]. Our market allows to enter irrigators holding rights (i.e. farmlands) in the hydrographic basin. Thus, only

[2]Hereinafter we will simply refer to these *tradable water rights* as *water rights*.

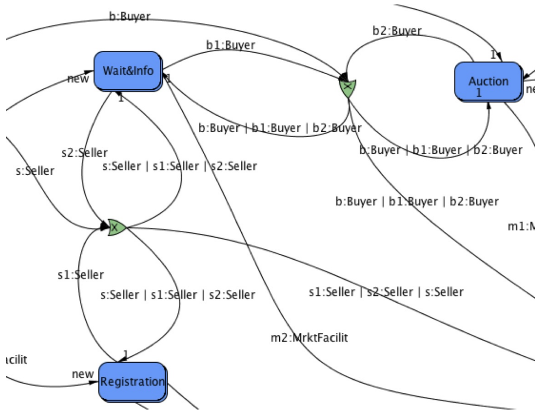

Figure 1: Extract of *v-mWater* performative structure. Boxes represent activities (Wait&Info, Registration, Auction1) and logic doors correspond to transitions.

farmlands' irrigators can participate in the negotiation.

3.2 Specification of interactions

We use an Electronic Institution to structure participants' interactions in the virtual environment. An Electronic Institution is defined by the following components: an *ontology*, which specifies domain concepts; a number of *roles* participants can adopt; several dialogic *activities*, which group the interactions of participants; well-defined *protocols* followed by such *activities*; and a *performative structure* that defines the legal movements of *roles* among (possibly parallel) *activities*. More specifically, a *performative structure* is specified as a graph where *nodes* represent both *activities* and *transitions* and are linked by directed *arcs* labelled with the roles that are allowed to follow them.

In the *ontology* of our water market scenario we have included concepts such as *water right*, *land* or *agreement*. Moreover, participants (both software agents and humans) can enact different roles. Thus, a *buyer* represents a purchaser of water rights, a *seller* is a dealer of water rights, a *market facilitator* is responsible for each market activity, a *basin authority* corresponds to the legal entity which validates the agreements, and an *institution manager* is in charge of controlling access to the market. To enter the institution, an agent must login by providing its name and the role it wants to play. Successfully loged-in agents are located at a default initial activity. From this activity, agents in *v-mWater* can join three different dialogical activities (see the *performative structure* in Figure 1): in the *Registration* activity water rights are registered to be negotiated later on; in the *Waiting and Information* activity, participants communicate each other to

Figure 2: Initial aerial view of v-mWater with three rooms (activities).

exchange impressions about the market and obtain information about both past and next negotiations; and finally, the negotiation of water rights takes place in the *Auction* activity. It follows a multi-unit Japanese auction protocol, a raising price protocol that takes, as starting price, seller's registered price. Then, buyers place bids as long as they are interested in acquiring water rights at current price.

Participants and specification elements of an Electronic Institution have their corresponding representation (visualization) in the 3D virtual environment. As an example, participants are represented as avatars whereas activities are depicted as rooms with doors in order to control the access (see Figure 2). Next section focuses on the infrastructure that supports such structured 3D virtual environment.

4 INFRASTRUCTURE

We have used VIXEE, the *Virtual Institutions eXEcution Environment* (xxx, 9999c), as a robust infrastructure to connect an *Electronic Institution* (EI) to different *Virtual World*s (VW). It allows to validate those VW interactions which have institutional meaning (i.e contemplated in the EI specification), and update both VWs and EI states to maintain a causal dependence. It also contemplates the dynamic manipulation of VW content.

Along this section we describe VIXEE architecture. It consists of 3 layers: normative control layer, visual interaction layer and casual connection layer (also referred in this paper as middleware), all of them depicted in Figure 3. We also provide in § 4.4 a description of the communication flow which enables human-agent interactions.

4.1 Normative control layer

The *Normative Control Layer* on the left side of Figure 3 is in charge of structuring interactions. It is composed by an *Electronic Institution Specification* and AMELI (Esteva et al., 2004), a general purpose EI engine. In order to generate an *EI specification* we use ISLANDER (Esteva et al., 2002), the EI specification editor that facilitates this task. Second, AMELI interprets such a specification in order to mediate and coordinate the participation of every agent within the MAS system.

Software agents (robot-alike icons on the left of Figure 3) have a direct connection to AMELI, which has a bidirectional communication with the middleware. This communication consists of two TCP ports. On one hand, an exit port is used to send AMELI messages to the middleware. On the other hand, one entrance port is used to receive VW actions from the middleware as AMELI messages.

4.2 Visual interaction layer

The *Visual Interaction Layer* represents several 3D virtual worlds. Human users (human-face icons on the right of Figure 3) participate in the system by controlling avatars (i.e. 3D virtual characters) which represent them in the virtual environment. Additionally, software agents from the Normative Control Layer can be visualised as bots in the VW (notice how dashed arrows in Figure 3 link robot icons on the left with bot characters within this layer).

This layer may host virtual world platforms programmed in different languages and using different graphic technologies. The common and main feature of all VW platforms is the immersive experience provided to their participants. VWs can intuitively represent interaction spaces (e.g. a room) and show the progression of activities that participants are engaged in. For example, an auction activity can be represented as a room with chairs for bidders, a desktop for the auctioneer and information panels to display dynamic information about the ongoing auction. In order to explore the virtual world, users can walk around as done in real spaces, but they can also fly and even teleport to other places in the virtual space. Participant interactions can be conducted by using multimodal communication (e.g. text chat, doing gestures or touching objects). The immersive experience can be still enhanced by incorporating sounds (e.g. acoustic signals when determining a winner in an auction).

The main components of this layer are VWs. We contemplate VW platforms based on a client-server architecture, composed by a VW client and a VW server. The former provides the interface to human participants. It is usually executed as a downloaded program in the local machine –e.g. Imprudence viewer (Imprudence, 2012)– or as a web in-

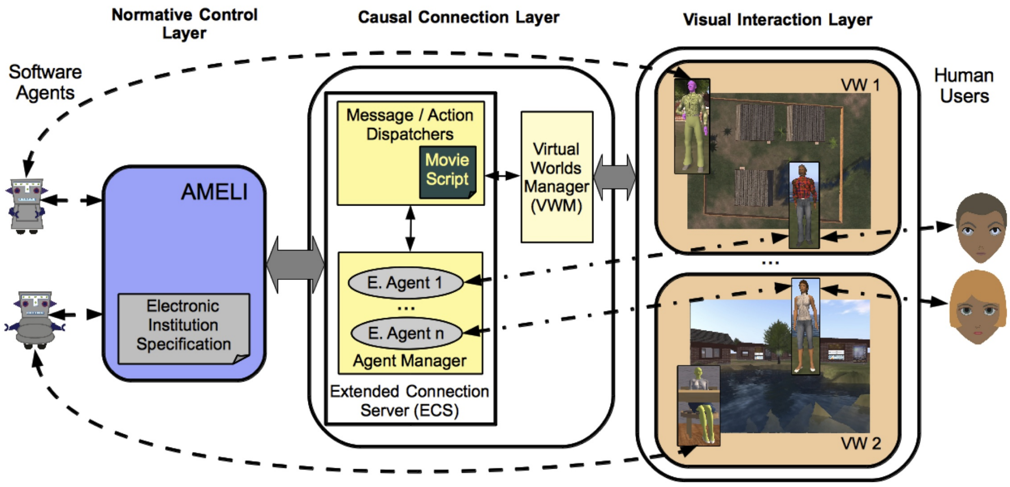

Figure 3: VIXEE Architecture. The Causal Connection Layer as middleware between the Normative Control Layer (populated by agents) and the Visual Interaction Layer (populated by 3D virtual characters).

terface. The latter communicates with the causal connection layer (see in next section) by using a standard protocol (e.g. UDP, TCP, HTTP). In particular, the scenario described in § 5 employs *Open Simulator*, an open source multi-platform, multi-user 3D VW server (OpenSimulator, 2012).

4.3 Causal connection layer

The *Causal connection layer* –or *middleware*– constitutes the main component of VIXEE (see Figure 3). Causal connection refers to a state-consistency relation, so that state changes are propagated along both communication directions. In one communication direction, it connects human participants from multiple VWs to the *Normative Control Layer* with the aim of regulating their actions. In the reverse communication direction, it supports the visualisation of software agent participants as bots in the VWs (representing their presence as well as their actions and their consequences). This layer is divided between the Extended Connection Server (ECS) and a Virtual World Manager (VWM). Next, we explain both components.

4.3.1 Extended connection server (ECS)

The ECS (left box inside the middleware in Figure 3) mediates all the communication with AMELI. It supports the connection of multiple VWs to one EI. This way, users from different VWs can participate jointly in the same VI. Moreover, ECS is able to catch those AMELI messages that trigger the generation of the initial 3D environment (e.g. build rooms and their furniture) and reset the world to a pre-defined state (e.g. clear information panels or close all doors)[3]. ECS main elements are the *Agent Manager* and *Message / Action Dispatchers*.

First, the *Agent Manager* creates an External Agent (E. Agent in Figure 3) for each connected (human-controlled) avatar. The external agent is connected to the EI with the aim of translating the interactions performed by the human in the virtual world. Therefore, AMELI perceives all participants as software agents.

Second, *Message / Action Dispatchers* (on top of *Agent Manager* in Figure 3) mediate both AMELI messages and virtual world actions. They use the so called *Movie Script* mechanism to define the mapping between AMELI messages and VW actions and vice versa. On one hand, a message generated from AMELI provokes a VW action so that the visualisation in all connected VWs is updated. On the other hand, for each institutional action performed by a human avatar in the VW (regulated by the EI), a dispatcher sends the corresponding message to AMELI by means of its external agent.

4.3.2 Virtual Worlds Manager (VWM)

The VWM (right box inside the middleware in Figure 3) mediates all VWs-ECS communications and dynamically updates the 3D representation of all connected virtual worlds. This is done by means of *Mes-*

[3]ECS manipulates VW content by means of two components: the *Builder* and the *Virtual World Grammar Manager*.

sage / Action dispatchers . On one hand, the VWM receives selected actions (corresponding to AMELI messages) from the *Message dispatcher* to update VWs' content accordingly. On the other hand, VWM filters VW actions and sends those with institutional meaning to the *Action dispatcher* who will communicate and, if necessary, update AMELI.

The VWM is composed by one VW proxy for each connected VW. Since different VW platforms can need a different specific programming language, these proxies allow to use such a specific language to communicate with the ECS. In our example scenario we use *OpenMetaverse* (OpenMetaverse, 2012) library to manipulate the content of *OpenSimulator*.

4.4 Human-Agent interactions

As previously introduced, our objective is to facilitate the user a structured hybrid virtual environment for serious purposes, such as e-commerce, e-government and e-learning. With this aim, we provide a VW interface for human participants whilst software agents are directly connected to the AMELI MAS platform and are represented as bots in the VWs.

We consider three types of interaction mechanisms: *illocution*, *motion*, and *information request*. First, *illocutions* are interactions uttered by participants within activities' protocols. Human avatars interact by means of illocutions by performing gestures and sending chat messages. Bot avatars can do the same except for those representing institutional agents, which can also send public messages by updating information panels. Second, *motions* correspond to movements to enter and exit activities. Human avatars show their intention to (and ask for permission to) enter and exit activities by touching the door of the corresponding room in the VW. As for bots, they are simply teleported between rooms. Third, *information requests* include asking to the institution for information about i) activities reachable ii) activities' protocols states and iii) activities' participants. These interactions have been implemented by both sending messages (e.g. the institution manager sends a private message to an avatar specifying that is not allowed to enter /exit an activity) and drawing on information panels (e.g. the state of an auction is indicated in a panel on a wall of the auction room).

In order to illustrate the communication flow of an interaction between agents and humans, here we describe two communication processes within a negotiation activity. In particular, we detail a bid placement (or, in other words, the interchange of bids) within an auction[4] (see Figure 4).

[4]For a correct understanding, we encourage the reader to follow the flow in Figure 3 as it is being explained in this paragraph.

Figure 4: Bot Buyer and human performing bidding gestures in a running auction.

The first communication process starts with the desire of a human participant to bid in an auction, so that s/he performs a raising hand gesture with his/her avatar. Then the VWM catches the action and communicates the gesture to the Extended Connection Server, which uses the *Action Dispatcher* to translate this gesture to the corresponding AMELI message *"bid"*. Afterwards, the *Agent Manager* in the middleware sends such a message to the normative layer. The message is sent by means of the participant's external agent. Next, AMELI processes the message and sends back a response with the result of the message (ok or failure) to the middleware. As a consequence, the middleware uses the VWM to cause (trigger) the action of the market facilitator sending a chat message with the response to all participants within the auction. Notice that, although the bid gesture is always performed by the human avatar, it does not mean that it was a valid action, so the confirmation message sent to the rest of participants is necessary for they to be aware of the action validity.

In the second communication process, a software agent directly sends a bid message to AMELI, since it is directly connected to the normative layer. Only if the message has been successfully performed in AMELI, it is reflected in the VW. To do so, the middleware receives the said message event from AMELI and translates it by means of the *Message Dispatcher* to the related bot avatar raising its hand. Thus, the human user can perceive bot's bid visually in its VW client. Overall, the human can bid and be aware of all other participants' bid placements. As we have seen, this mechanism allows agents and humans in the same auction activity to interact in a structured and seamless way.

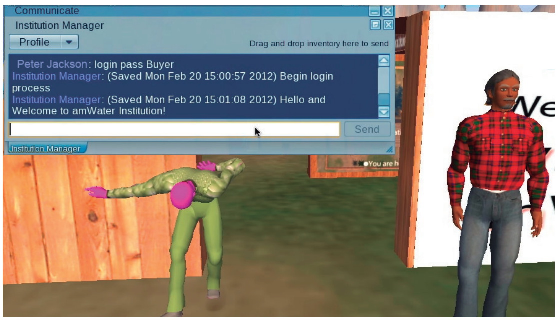

Figure 5: Human avatar login: interaction with a software agent (on the left) by means of a chat window.

Figure 7: The inside of the *Waiting and Information* room.

5 EXECUTION EXAMPLE

This section is devoted to briefly describe our *v-mWater* scenario, were human avatars interact with several bot characters. All bots are bold and have differentiated artificial skin colours that represent their roles (see Figures 4, 5, 6 and 7).

Figure 2 shows three rooms generated in the VW, one for each activity in the EI defined in § 3.2. The institution precinct is delimited by a fence with an entrance on its left side, where the *Institution Manager* restricts the access.

In our example execution, Peter Jackson is a user that controls his human avatar and requests access to the market as a buyer by sending a login message *"login *** Buyer"* to the *Institution Manager*. The syntax of this login message is *"login password role"* and is sent through its private text chat window. The *Institution Manager* validates this login and, as Figure 5 depicts, performs a welcome gesture in response.

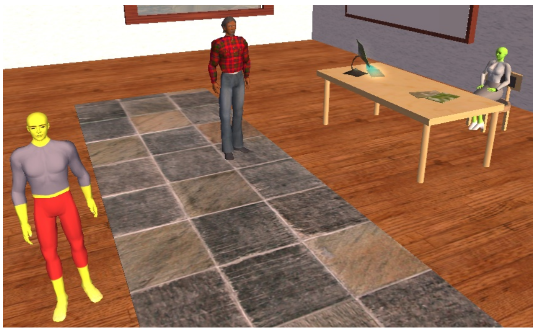

Figure 6: Human seller in the *Registration* room.

The access to the *Registration* room (see Figure 6) is limited to participants playing a seller role. There, sellers can register a water right by sending a register command through the private text chat to the *Market Facilitator* sat at the desktop. This command's syntax is *"register ⟨water_right_id⟩ ⟨price⟩"*, where ⟨*water_right_id*⟩ corresponds to the water right identifier and ⟨*price*⟩ is the starting price of the negotiation in €. Next, the *Market Facilitator* confirms that the registration is valid and sends back the corresponding *"idRegister"* (otherwise, it would send an error message). All correctly registered water rights will be auctioned later on.

All participants are allowed to enter the *Waiting and Information* room (see Figure 7). Several waiting sofas are disposed in this room, a map of the basin is located on its left wall and the desktop located at the end is designated to be used by the *Market Facilitator*. Behind it, one dynamic information panel shows a comprehensive compilation of relevant information about last transactions. The *Market Facilitator* indicates every new transaction updating the information panel. Alternatively, participants can approach the *Market Facilitator* and request for information about last transactions. This is done by sending a private chat message *"trans"*. Similarly, they can also request for information about next water rights to negotiate with the private chat message *"nextwr"*. In both cases *Market Facilitator*'s response goes through the same chat.

Buyer participants can join a negotiation activity by requesting the entrance to the *Auction* room (see Figure 4). If their access is validated, they can take a sit at one of the free chairs disposed in the room. Two desktops located at the end are reserved for the *Market Facilitator* (left) and the *Basin Authority* (right). Then, the bidding process explained before (in § 4.4) takes place. Winner/s will request a desired quantity of water from the *Basin Authority* through a private chat window. As a result, the *Basin Authority* notifies the valid agreements to all participants with a gesture and updates the information in the designated panel. Although some details are omitted, we can see that, despite the inherent complexity of the *Auction* activity, it has been designed in a way so that a human participant can easily place bids and intuitively follow the course of a negotiation.

6 USABILITY EVALUATION

This section evaluates our *structured hybrid Virtual Environment* by means of a usability test that follows the widely-used test plan from (Rubin and Chisnell, 2008). Therefore, we first define general test objectives and specific research questions that derive from them. Next, we detail chosen test participants and the followed methodology. Last, we describe and discuss obtained results both at qualitative and quantitative levels.

6.1 Test objectives

The main goal of this usability test is to assess the usefulness of our *structured hybrid Virtual Environment*, that is, the degree to which it enables human users to achieve their goals and the user's willingness to use the system. This goal can be subdivided in the following sub-goals:

- Assess the *effectiveness* of *v-mWater*, i.e the extent to which its 3D interface behaves in the way that users expect it and the ease with which users can use it to do what they intend to.
- Assess the *efficiency* of *v-mWater*, i.e. the quickness with which the user goals can be accomplished accurately and completely.
- Identify *problems/errors users encounter/make* when immersed on such a hybrid and normative (structured) 3D VE.
- Assess *user's satisfaction*, that is, their opinions, feelings and experiences.
- Open some discussion about the hypothesis that *users' features* of age, gender or skills (with computers as well as with VEs) may affect both user *ability to reach the goal* and user *experience*.

With all these objectives in mind, we have defined a test task that consists on searching for information about last transactions in the market and registering (for selling) a water right. This structured task is in fact composed of four subtasks:

i) *Understand the task and figure out the plan* (two out of three rooms have to be visited in a specific order) required to perform the task.

ii) *Get specific information about the market transactions* at the *Waiting and Information* room. This can be accomplished by checking the information panel or rather by talking to the Information bot found at the desk.

iii) *Work out the required registration price*, which has to be 5€ higher than the price of the most recent transaction.

iv) *Register the water right* at the *Registration* room, by talking to the Registration bot, found at the desk in the same room.

6.2 Research Questions

With *v-mWater* being a functional prototype, we wanted to answer some questions related to how usable it is, how useful this VE proves to be to different users, and more generally, the user's willingness to perform *e-government* services in Virtual Environments. Given the test objectives introduced in the previous section, we address several research questions that derive from them. These questions are divided in two categories. The first category is closely related to the task users are asked to perform in the virtual environment:

RQ1: Information gathering How fast does the user find the information needed once s/he enters the *Waiting and Information* room? Was the information easy to understand? How did the user obtain that information? (reading a panel or interacting with the agent).

RQ2: Human-bot interaction Is the registration desk (and bot) easy to find? How pleasant is the interaction with the bot? Does the user values knowing which characters are bots and which are humans?

RQ3: Task completion What obstacles do sellers encounter on the way to the *Registration* room on the VE? What errors do they make when registering a water right? How many users did complete the task?

Answers to questions in this first category give us data about effectiveness, efficiency and errors doing concrete tasks in the environment. The second category is more general and focuses on user's ability and strategies to move around a 3D virtual space, learnability for novice users, and perceived usefulness and willingness to use Virtual Environments for online *e-government* procedures:

RQ4: User profile influence Does the user profile (age, gender, and experience with computers and VEs) influence perceived task difficulty, user satisfaction and user immersiveness?

RQ5: VE navegability Which strategy does the user take to move between rooms? Does the user notice (and use) the teleport function? Even noticing it, does she prefer to walk around and inspect the 3D space?

RQ6: Applicability to *e-government* How do users feel about 3D *e-government* applications after the test? Would they use them in the future?

6.3 Participants

We have recruited 10 participants. They form a diverse user population in terms of features such as age, gender, computer skills and experience on 3D virtual environments/games. Participants' ages were from 18 to 54, within this group we find users that have grown with computers and users that have not, therefore we can study how age influences efficiency, perceived easiness, usefulness and their predisposition to use such a 3D and hybrid virtual space for *e-government* related tasks. We also pay special attention to users' computer skills and experience in 3D virtual environments as it can influence their ability to perform required tasks. Table 1 shows details on participants age, gender, computer skills ('basic', 'medium', 'advanced') and virtual environment/games experience ('none', 'some', 'high'). The classification for computer skills was: 'basic' for participants which use only the most basic functionalities of the computer, such as web browsing, text editing, etc.; 'medium' for users with a minimum knowledge of the computer's internal functioning and who use it in a more complex way such as gaming; and 'advanced' for participants who work professionally with computers, i.e. programmers. Regarding virtual environment skills, 'none' were users who have never used a VE, 'some' described users who have tried it occasionally, and 'high' for users who often use a VE. Notice that although most skills are uniformly distributed, VE experience is strongly biased towards VE newcomers.

Table 1: List of participants characterised by their age, gender and experience (exp).

Name	Age	Gender	PC exp	VE exp
P1	18	Female	Medium	Some
P2	19	Female	Medium	High
P3	20	Male	Advanced	Some
P4	25	Female	Medium	None
P5	25	Female	Medium	None
P6	28	Female	Advanced	None
P7	39	Male	Advanced	None
P8	40	Male	Medium	None
P9	53	Male	Basic	None
P10	54	Female	Basic	None

6.4 Methodology

The usability study we conducted was mainly exploratory, but somehow summative. We used the Formative Evaluation method (Bowman et al., 2002b), which fitted our interests at this early iteration of the prototyping of our VE scenario (moreover, it is the first test we conduct with *v-mWater*) and we were mostly interested in finding relevant qualitative data about the usability of the system. Nevertheless, since the application itself is already a functional prototype, we also took into account some quantitative measures.

The evaluation team was composed by a moderator and an observer. The former guided the user if needed, encouraged him/her to think-aloud, introduced the test session, and gave the user any material needed, such as the consent-form and the post-test questionnaire. The latter took any needed notes regarding the test sessions.

The tests took place at users' locations: half of the participants did the test at their home and the other half at their workplace, on a separate room. The equipment needed was 2 computers, one which acted as the server and a second one for the user to do the test with, just acting as the client and recording both the desktop and the sound during the task.

All participants where requested to perform previously described task. Specifically, they were told: *"act as a seller, and register a water right for a price which is 5€ higher than the price of the last transaction done"*. Recall that, in order to do the task properly, participants would then have to visit the *Waiting and Information* room, check the price of the last transaction (by asking the bot or checking the information panel), and afterwards head towards the *Registration* room and register a water right at the correct price by interaction with the Registration bot.

The test protocol consists of 4 phases:

1. *Pre-test interview*: We did welcome the user, introducing him/her to the test and asking questions regarding their experience with (and opinion about) *e-government*.
2. *Training*: We had the user play through a little demo to teach him/her the controls, teach how to interact with objects and avatars alike and show the differentiation between bots and human characters, also with an explanation of how to interact with the bots (chatting with a sort of command system). This training part was fully guided, since the moderator explained the user what to do at each step of the demo, except at the end, when the user could freely roam and interact with the demo scenario until s/he chose to begin the test (by exiting the demo scenario).
3. *Test*: The user performed the test task without receiving guidance unless s/he ran out of resources. Meanwhile the moderator encouraged the user to think-aloud (by telling him/her to describe actions and thoughts while s/he did the test).
4. *Post-test questionnaire*: The user is given a ques-

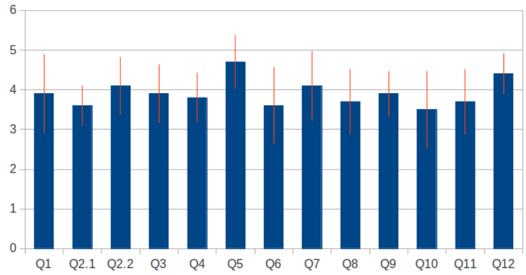

Figure 8: Post-test questionnaire results. X axis: questions from Table 2. Y axis: average (and standard deviation) values.

tionnaire with qualitative and quantitative questions regarding *v-mWater* and also regarding the application of VEs to *e-government* tasks (see Figure 8).

6.5 Results and discussion

In this section we discuss usability issues identified after the analysis of data gathered during the test. We will go through the research questions defined in § 6.2. The answers to each of them come from different sources: a combination of the post-test questionnaire; comments given by the users; notes took by the observer; and the review of the desktop and voice recordings that were taken during the test (i.e. while participants were performed the task).

Table 2 summarizes the 12 questions in the post-test questionnaire, and Figure 8 depicts a compilation of users' answers. There, X axis shows each of the post-test questions and the Y axis shows average values of answers considering a five-point Likert scale. This scale provides 5 different alternatives in terms of application successfulness ('very bad'/'bad'/'fair'/'good'/'very good'), where 'very bad' corresponds 1, and 'very good' to 5. Standard deviation values are also provided.

Overall, the quantitative results we obtained from the questionnaires were very satisfactory, with all average answers higher than 3.5 (standard deviation lower than 1.0). Highest rated responses (whose values were higher than 4.0) were associated with the easy distinction of bots and human controlled characters (Q5) and the overall satisfaction of the user (Q12). On the other end, lowest rated responses (with 3.5 values) were related to the comfortability when walking within the environment (Q2.1), the command system used to chat with the bots (Q6), and the idea of using a 3D virtual environment for similar tasks (Q10).

From both the qualitative measures that the user gave at the open question of the post-test questionnaire as well as when debriefing with the evaluating team, we extracted a number of relevant aspects of the *v-mWater* system. Firstly, users like its learnability, its immersiveness, and how scenario settings facilitate task accomplishment. Moreover, users like 3D visualization although as of today, it is too soon for them to imagine a VE being used for everyday tasks, since it is hard to imagine, unfamiliar, and in some cases users wouldn't fully trust on it. At the same time, the overall opinion of the system was positive and some users clarified that they were not entirely comfortable using the application , but they would easily become used to it; since it was highly learnable and safe to use.

Table 2: Post test questionnaire

Question Number	Brief description
Q1	Situatedness and movement in 3D
Q2 (Q2.1, Q2.2)	VE walking (2.1) and teleport (2.2) comfortability
Q3	Info gathering (panel/bot)
Q4	Human-bot interaction
Q5	Bot visual distinction
Q6	Chat-based bot communication
Q7	Task easiness
Q8	Immersiveness in 3D
Q9	Improved opinion of 3D VWs
Q10	Likeliness of future usage
Q11	3D interface usefulness
Q12	Overall system opinion
open question	User's comments

Usability criteria, such as effectiveness, efficiency and errors have been analysed answering the research questions from first category introduced in § 6.2.

RQ1: Information gathering

The information that the user had to obtain in subtask ii) could be gathered from 2 sources: the information panel and the Information bot, both located at the *Waiting And Information* room. During the test, the majority of the users, except two of them who did not enter this room, walked directly towards the information panel and/or the information desk (where the bot was located). These users could easily read the information from both sources. Answers of Q1 and Q3, both with an average close to 4, reinforce previous statement.

RQ2: Human-bot interaction

Users should interact with bots in different subtasks (ii and iv). The high average of Q4 indicates that the user had a good overall impression about human-bot interaction. Nevertheless, Q6 denotes that users were uncomfortable with the technique, a command-based system, used during the dialogue with the bot. Analysing Q5, with an average of 4.7, we can state that participants found it almost imperative to know when they were facing a bot.

RQ3: Task completion
Overall, participants found it easy to complete the task (as Q7 indicates with an average of 4), and they took an average of 4.46 minutes. Users have not found any obstacles that prevented them from completing the task. Regarding errors that users committed during the task completion, some users did not always go to the right destination (building), but they always realised their mistake and were able to get to the correct destination. Another type of error relates to the chat-based interaction with bots; as Q6 indicates, where the average of the answers was 3.6. Users with low computer skills had some kind of trouble when interacting with the bot because of the strict command-based system. Nevertheless, the users found this communication system highly learnable. Related to the effectiveness of the application we have measured it re-viewing the desktop recordings. Considering the structure of the task that has been detailed in § 6.1, the percentage of users that completed the corresponding sub-tasks were:

i) 80% understood the task correctly. Only 20% of users did not figure out they had to check prices before registering their water right.
ii) 80% of users gathered the information correctly (the rest skipped that step).
iii) 70% of users calculated the price properly.
iv) 100% completed the registration subtask, i.e. all participants registered their water right.

Below, we give a brief discussion about user profile influence on perceived task difficulty, satisfaction, usefulness and immersivenes, and analyse more general usability aspects of our system such as the user's ability to move around a 3D virtual space; or perceived usefulness of Virtual Environments for on-line *e-government* procedures.

RQ4: User profile influence
This question was answered by analysing the results from our post-test questionnaire in terms of user features. From the point of view of age, participants are equally balanced. As the age increases it also does the difficulty to use the application, although the satisfaction also increases. Surprisingly, the youngest users found the application less useful than the older ones (this may be due to their higher expectations from 3D VE). Related to users' experience with computers, users with the lowest experience had clearly a harder time using the arrow controls to walk around the 3D space. Additionally, this group found difficult both the interaction with the bots and the task completion. Similarly, the immersion grows as the experience with computer grows.

RQ5: VE navigability
Navigation in our VE has proven to be relatively easy, since users' average opinion was 4 (Q1). They did not roam in any occasion as it has been appreciated on the recordings. Users who found out they could teleport were comfortable using it, as they reflected on the post-test questionnaire (Q2.2) and also by some of their comments.

RQ6: Applicability to *e-government*
Users' opinion about virtual environments had improved after doing the test (Q9), since they answered with an average value of 4. When asked about their intention to use a similar system for similar tasks in the future (Q10), users answered an average of 3.5, which means that they have a relative good opinion about the usefulness of the application. Finally, users reported that the 3D interface had helped them in achieving their goals during the test, as Q11 shows with an average value of 4.

7 CONCLUSIONS

In this paper we have explicitly structured participants' interactions in hybrid (humans and software agents) virtual environments. We have presented an example of scenario in an e-government application (*v-mWater*, a *v*irtual *m*arket based on trading *Water*), and evaluated its usability.

We have also described the execution infrastructure that supports this hybrid and structured scenario where both human and bots interact each other and with the environment. Furthermore, we characterize different interaction mechanisms and provide human users with multi-modal (visual, gestual and textual) interaction. In our usability study, we have payed special attention to how users perceive their interaction with bots.

The usability evaluation results provide an early feedback on the implemented scenario. *v-mWater* is perceived as a useful and powerful application that could facilitate everyday tasks in the future. Users like its learnability, its immersiveness, and how scenario settings facilitate task accomplishment. In general, users have well completed the proposed task and were able to go to the right destination in the scenario. After doing the test, users improved their opinion about 3D virtual environments. In addition, the overall opinion of the human-bot interaction is positive.

Nevertheless, there are some inherent limitations of interface dialogs and interactions. Some users are not comfortable using the command-based bot dialog and find difficult to move their avatar in the 3D environment. Thus, a future research direction is to define new forms of human-bot interactions, using multimodal techniques based on voice, or sounds and tactile feedback supported by gaming devices. We also plan to incorporate assistant agents to help humans participate effectively in the system, and perform a comparative usability study to gain insight into assistants' utility.

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