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CASE STUDIES USING MULTIUSER VIRTUAL WORLDS AS AN INNOVATIVE PLATFORM FOR COLLABORATIVE DESIGN

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SUMMARY: *To some extent, design can be described as a process concerned with changing the state of an environment through purposeful and constrained decision making that requires exploration, creativity and learning. The broad discipline of design incorporates the study of design methodology, technologies for design and design thinking. Design projects in the Architecture, Engineering and Construction (AEC) domains generally require efficient collaboration between designers from different specialties involved in the entire lifecycle of a project, and often based at different locations. In addition, there is emerging potential for human-computer co-creativity in the design process. This paper investigates the innovative use of emerging multiuser virtual world technologies for supporting human-human collaboration and human-computer co-creativity in design. The paper defines three conceptual technology spaces that describe the different aspects of virtual worlds that make them useful as platforms for certain types of collaborative design: design tools for modelling new artefacts, support for communication, and the ability to incorporate artificial models of cognitive design processes. In order to support the conceptual technology spaces for multiuser virtual worlds, four case studies were conducted and examined in the field of collaborative design using multiuser virtual worlds. Analysis of these case studies reveals the current strengths and limitations of multiuser virtual worlds for supporting human-human collaboration and human-computer co-creativity in design activities.*

KEYWORDS*: multiuser virtual worlds, design, collaborative design, design computing, design cognition, agents, artificial intelligence*
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1. INTRODUCTION

Design can be described as a process concerned with changing the state of an environment through purposeful, constrained decision making requiring exploration, creativity and learning (Gero, 1992). The broad discipline of design incorporates the study of design methodology, technologies for design and design thinking. This paper analyses the role of virtual worlds as an emerging and promising technology for supporting design and design thinking in a collaborative context. Specifically, we focus on the potential of virtual worlds to support two aspects: human-human collaboration and human-computer co-creativity.

Design tools based on 3D parametric modelling are gradually gaining the sophistication that is required to support the development of complex design models, and to incorporate design automation practices, without limiting the functions and forms of the design artefacts. Major components of the current building industry, for example, are evolving to take advantage of the potential benefits of integrated 3D parametric modelling. The development of Building Information Models (BIM) or building product models (Eastman, 1999) that extend parametric models to include non-geometric properties is an ongoing research area.

The main driver behind using virtual worlds for design is that 3D virtual worlds represent a new technology that permits exploration of new approaches to form generation and simulation in real-world design. In addition, virtual worlds can be designed places in their own right for social interaction and collaboration (Linden, 2009; There, 2009), entertainment (Blizzard, 2009; ElectronicArts, 2009), business (Coca-Cola, 2007), charity work (American-Cancer-Society, 2008), defence applications (Bohemia-Interactive, 2009) and education (Gu et al, 2009). Another driver is that 3D virtual worlds are platforms that permit experimentation with models of cognitive design processes using bots (agents). This means that virtual worlds are a potential platform for supporting human-computer co-creativity because the virtual world platform permits interactions between humans and artificial agents that are programmed to support the creative design process. Virtual worlds can also support mass participation on a very large scale, with some worlds supporting thousands or hundreds of thousands of participants. This level of intelligence and interactivity is not readily available in BIM and other mainstream CAD technologies.

Virtual worlds can also be used to develop an understanding of human collaborative processes in design by providing designers with a co-designed virtual space for collaboration and logging their communications and the actions they perform during design. Understanding design cognition or design thinking is a challenging task, as it requires understanding and modelling human creative processes (Eastman, 2000). However, understanding design cognition has great practical benefits. Understanding creative design provides insights into how humans create new ideas and products. Understanding the processes used in design and the skills required to realise particular tasks permits better teaching of design and, ultimately, produces better human designers. Models of human cognitive processes for creative design can be embedded in artificial agents in virtual worlds, and can provide inspiration for tools that better support and enhance the design process.

The remainder of this paper is organised as follows: Section 2 reviews current virtual world technologies and examines the range of virtual worlds as a technology space that can support design. We identify three key facets of virtual worlds that can support design and design cognition: their design tools, communication tools, and support for artificial intelligence. Sections 3 examines a number of case studies of design research and teaching that uses virtual world platforms, with respect to the facets of virtual worlds discussed in Section 2. Section 4 concludes by discussing some of the recent progresses and advances in virtual world technologies, the implications they may have and the challenges they pose for future design collaboration, research and teaching.

2. TECHNOLOGY SPACES OF MULTIUSER VIRTUAL WORLDS

Multiuser virtual worlds are computer-based, networked, simulated environments. Various virtual worlds exist that simulate realistic (Linden, 2009) or entirely fictional (Blizzard, 2009; CCPGames, 2009; ElectronicArts, 2009) environments. Users inhabit and interact with virtual worlds using avatars. Depending on the virtual world, users can use their avatars to interact with each other or elements of the virtual environment. These elements may include the terrain or ambient environment, artefacts such as plants or furniture, and computer-controlled avatars.

The earliest virtual worlds were text-based, multiuser dungeons (MUDs) and object-oriented MUDs (MOOs). MOOs such as LambdaMOO (Rex, 2006) are distinguished from MUDs by the ability for users to program the MOO server, expanding and changing how it behaves for all users. More recently, improvements in computer graphics and networking capabilities have made large-scale, persistent, multiuser 3D virtual worlds possible. Current examples include *Active Worlds* (ActiveWorlds, 2007), *Second Life (Linden, 2009)*, *There* (There, 2009), *Moove Online* (moove, 2009), *Kaneva* (Kaneva, 2009), *World of Warcraft* (Blizzard, 2009), *EVE Online* (CCPGames, 2009), *Ultima Online* (ElectronicArts, 2009) and others.

Key features of these worlds are the online social experience they offer and the capacity for users to create content. This may include designing terrain, buildings, rooms, furniture, avatars, clothing or other artefacts. The support for collaborative creativity offered by multiuser virtual worlds forms a foundation for their support of design activities.

Virtual worlds are multi-faceted technologies. Their history can be considered to extend as far back as early as single-player computer games such as *SpaceWar* (Russell, 1962) and multiuser, text-based games such as *Colossal Cave Adventure* (Crowther, 1975). The facets of virtual worlds that could be considered include their graphics technology, network structure, persistence, theme, communication tools, design tools, artificial intelligence, economy, user types and governance. These facets differentiate multiuser virtual worlds from computer-aided design (CAD) tools such as *Maya*, *3D Studio Max*, *AutoCAD* and *Revit* which place the most focus on the graphics technology and design tools facets and little or no focus on facets such as economy and governance.

TABLE 1 summarises the facets of multiuser virtual worlds and compares virtual worlds and CAD software through these facets. In this paper we focus particularly on three facets of virtual worlds that make them useful as platforms for human-human collaboration and human-computer co-creativity in design: design tools for modelling new artefacts, support for communication, and the ability to incorporate artificial models of cognitive design processes. The following sections define and describe these facets as technology spaces. The remainder of the paper is concerned with understanding how existing virtual worlds fit in these spaces and identifying where future work on virtual worlds might further support their use in design-related fields.

TABLE 1. Facets of multiuser virtual worlds, and examples of how they distinguish between virtual worlds and computer-aided design (CAD) packages.

Facet	Multiuser Virtual Worlds	Computer Aided Design Packages
Graphics technology	Can be text-based, 2D graphics, 2.5D (isometric), 3D	2D and 3D graphics with different visualization modes (e.g., wireframe, solids, etc.)
Design tools	Aimed at non-expert designers, often simplified to support this.	Aimed at design detailing by expert designers for different specialties. Usually complex and highly expressive in geometrical modelling.
Theme	From realistic to imaginative: simulation sports, adventure, science-fiction, fantasy, world-building, role-playing etc.	Often professionally oriented for industries such as architecture, industrial design, structure/mechanical engineering and etc.
Persistence	World persists online even when users logoff. Databases save personal items, but no save facilities for world state.	World shuts down when users close the applications. World state can be saved and exchanged between different CAD packages (interoperability) .
Network structure	Online, massively multiuser	Local single user or internet based asynchronous (e.g., Navisworks) or synchronous (e.g., ArchiCAD Teamwork) collaborative modes among multiple users
Communication tools	Synchronous and asynchronous, including text chat, voice, graphical communication cues, calendars, group management tools. Avatars represent the participants.	Synchronous and asynchronous, often without the representation of the participants.
User types	Achievers, explorers, socialisers, killers (Bartle, 2003)	Achievers: specifically designers
Artificial intelligence	Support for computer-controlled avatars and scripted object behaviours	Some support for scripted behaviours
Economy	Resources for design open to the wider public that can cost real-world money and designs themselves can be sold in-world.	Design resources are often available exclusively to design professionals. Designs can be sold in the real-world.
Governance	World designers impose global laws (terms of use agreement). Emergent local self-governance of small areas by users	Terms of use agreement and other business contacts.

2.1.Design Tools

A subset of virtual worlds, which we classify as *open-ended* virtual worlds, make available modelling tools to permit users to change how the world behaviours for all users. The earliest such examples include LambdaMOO (Rex, 2006) which provides libraries of verbs to permit users to change the text-based description of the virtual world. More recent virtual world platforms permit users to design new 3D artefacts to modify the environment.

The tools for designing these 3D artefacts are themselves varied and also differ in the way they are connected to the virtual world. **Error! Reference source not found.** depicts these differences diagrammatically as a technology space for design tools. The following paragraphs consider the spectrum of tools in detail.

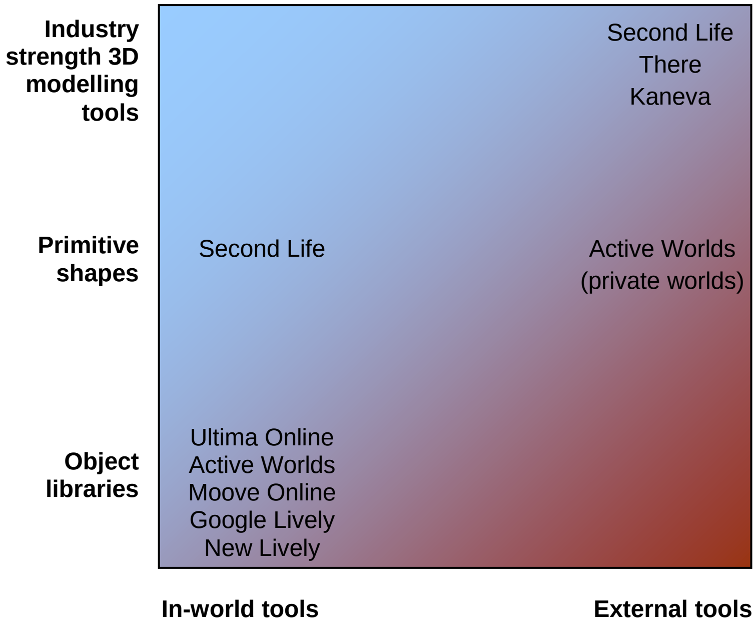
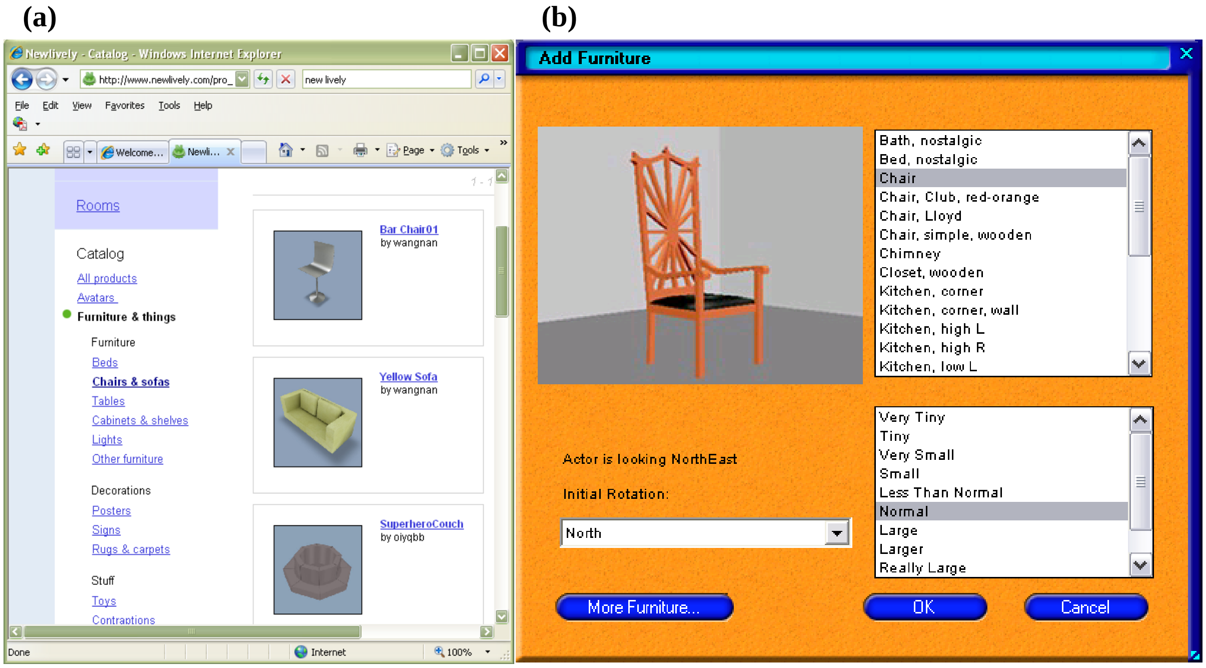


FIG. 1:. Technology space for design tools.

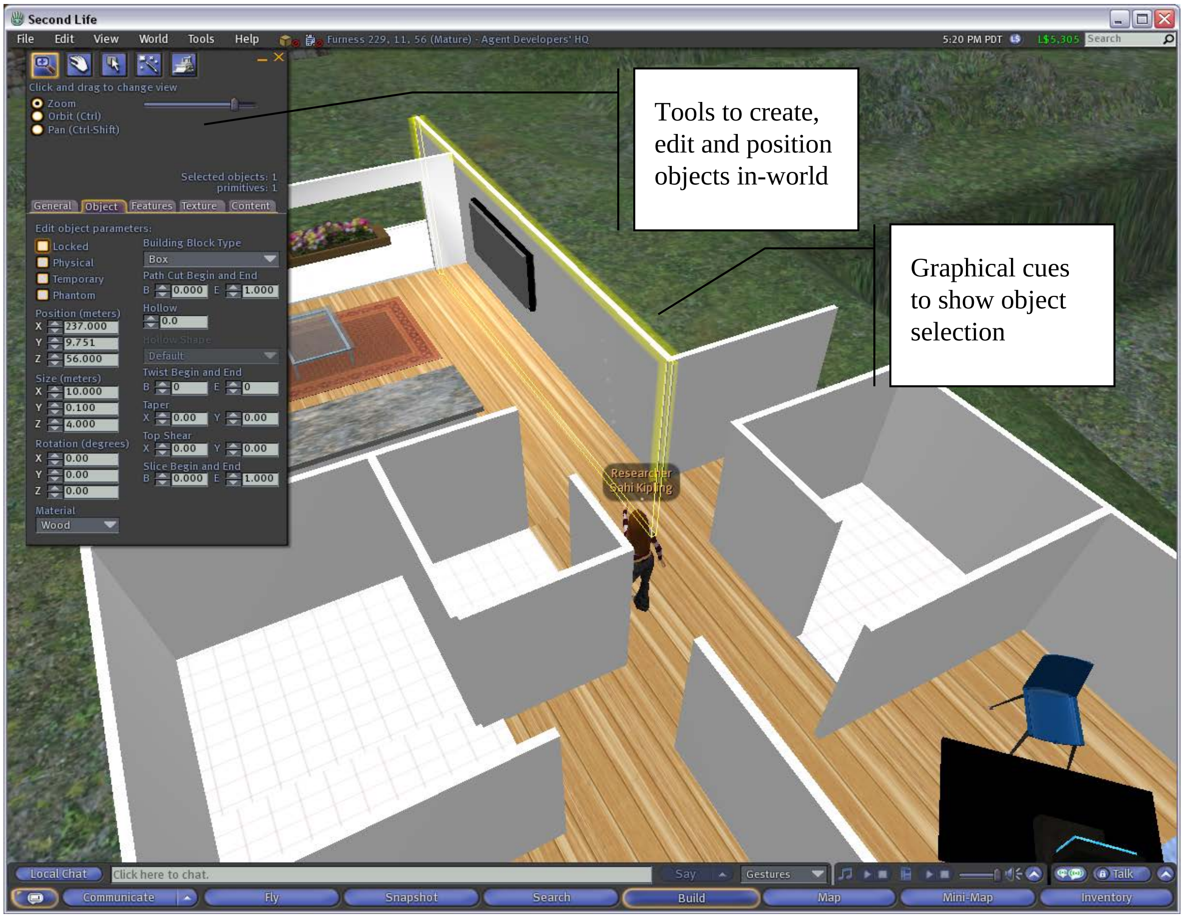
Object libraries provide a list of pre-defined objects that can be placed together in the world as design representations. *Google Lively* (Google, 2009) and its successor *New Lively* (NewLively, 2009), for example, provide library objects for rooms, furniture, landscape elements and so on, as shown in FIG. 2. Users are limited to using objects in the library only. Object libraries tend to be in-world tools.



Actor is looking NorthEast

Initial Rotation: North

FIG. 2.: Object libraries from (a) Google Lively and its successor New Lively and (b) Moove online.



Selected objects: 1
primitives: 1

Edit object parameters:

☐ Locked
☐ Physical
☐ Temporary
☐ Phantom

Position (meters)
X 237.000
Y 9.751
Z 56.000

Size (meters)
X 10.000
Y 0.100
Z 4.000

Rotation (degrees)
X 0.00
Y 0.00
Z 0.00

Material: Wood

Building Block Type: Box

Path Cut Begin and End: B 0.000 E 1.000

Hollow: 0.0

Hollow Shape: Default

Twist Begin and End: B 0 E 0

Taper: X 0.00 Y 0.00

Top Shear: X 0.00 Y 0.00

Slice Begin and End: B 0.000 E 1.000

Tools to create, edit and position objects in-world

Graphical cues to show object selection

FIG. 3. (a) In-world design tools in Second Life.

Primitive-based design tools – such as those in *Second Life* – allow the design of objects with forms determined inside the world by selecting geometric primitives and manipulating their parameters. The geometric features of the design can be adjusted within the world at any time, and object permissions can be changed to permit collaborative manipulation of a single object by multiple designers. *Kaneva* also offers basic in-world manipulation of objects and their textures, although the underlying structure of the object must be designed using an external tool. In contrast, in-world tools are integrated with the virtual environment so users can design while they are logged into the virtual world. Objects are often designed 'on location' against a backdrop of other objects at their intended location. Examples of the in-world design tools in *Second Life* are shown in FIG. 3. Examples of the *Active Worlds* and *Kaneva* in-world tools for modifying externally created objects are shown in FIG. 4.

Industry strength 3D modelling tools are now more commonly supported by virtual worlds as an external tool. Users design locally on their personal computer then log into the virtual world and upload their work to the world. In this case objects are often designed individually and in isolation from other objects. *Second Life* and *Kaneva* are examples of a virtual world that permits third party software to be used externally and designed objects uploaded. External tools that can be used with these virtual worlds include *Maya* and *3D Studio Max*. These tools are generally the most powerful and expressive tools commonly used in the design industries. However because they are used externally they cannot be combined with in-world collaboration and objects are not designed in-situ.

2.2.Communication Tools

Virtual worlds enable communication and collaboration between members of a design team that are geographically distributed (Bouras et al., 2007). As with design tools, current virtual worlds provide different tools for communication and collaboration. Once again these may be either integrated with the virtual world or third party software, as shown in FIG. 5. Different tools provide different levels of workspace awareness.

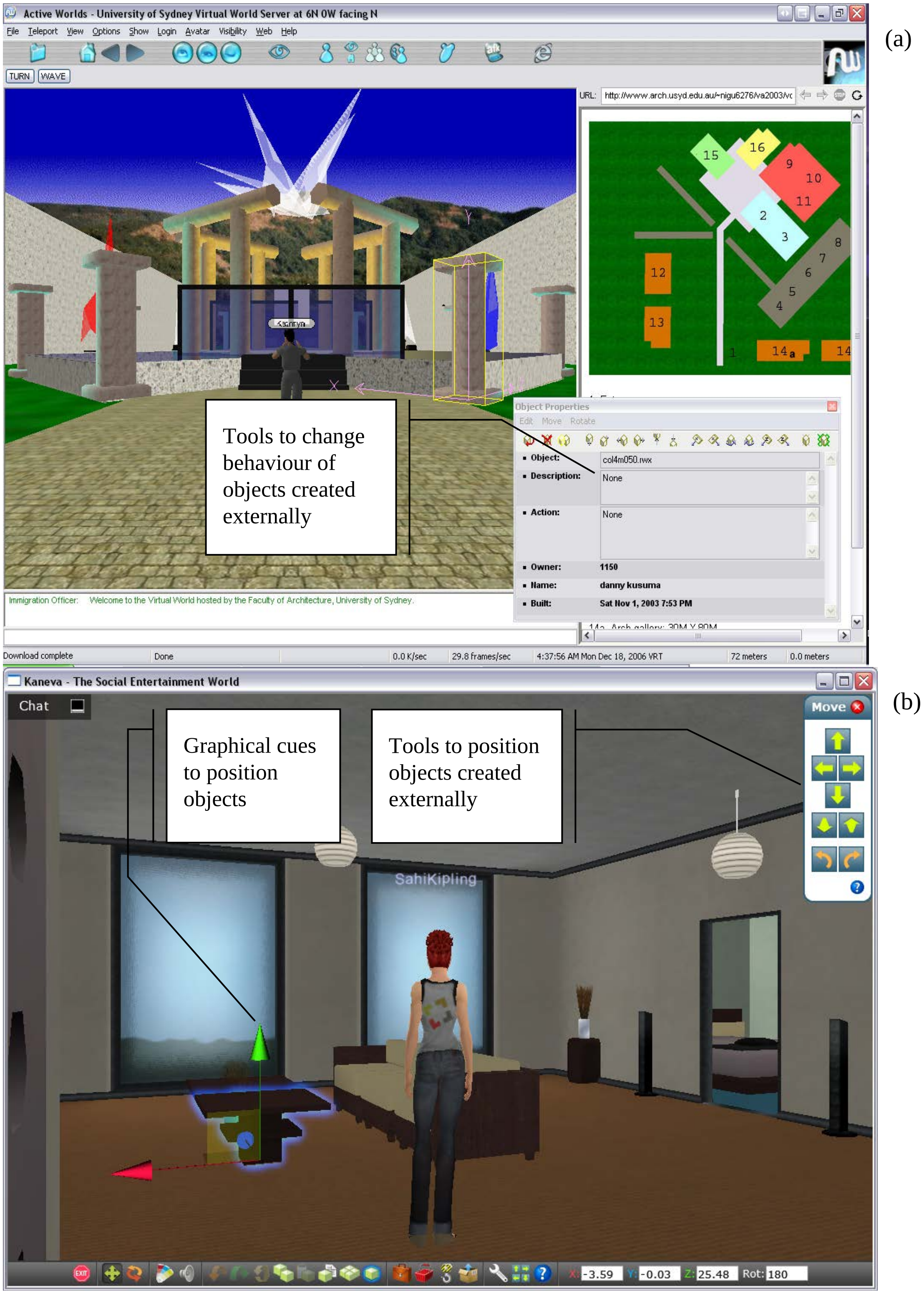
Text-based chat. The earliest virtual worlds permitted interaction and collaboration only via text-based chat. This is still the basic communication tool in current virtual worlds (Linden, 2009; There, 2009).

Voice communication. Later virtual worlds support both text-based chat and voice-based communication (Blizzard, 2009; Linden, 2009).

Graphical cues have been included in later virtual worlds to stimulate workspace awareness. *Second Life*, for example, provides workspace awareness through techniques such as consequential communication and feed-through. In consequential communication, the characteristic movements of an action communicate its character and content to the collaborators (Segal, 1995). For example, when a designer communicates by typing in *Second Life*, his or her avatar also appears to be typing to inform other collaborators of the corresponding action.

In feed-through, the feedback produced when 3D models are manipulated provides collaborators with clues about the manipulations (Dix, Finlay, Abowd, & Beale, 1993). For example, when a designer is manipulating an object in *Second Life*, a light blob links the object to the designer's avatar. This connection shows his or her collaborators the design actions that are currently being undertaken. These features permit designers to gain better awareness of each other's actions and be more engaged in collaborative tasks. In contrast, some other platforms such as *Active Worlds* do not support this sort of workspace awareness which can make coordination of collaborative actions more difficult.

Organisational tools: As the use of virtual worlds increases, new types of tools are being added to permit users to manage very large social groups. These include tools for creating and managing specialised groups, called simply 'groups' in *Second Life* or 'guilds' in *World of Warcraft.* The tools permit the definition of a group charter, the invitation of new group members and the assignation of roles and responsibilities to members of the group. Other organisational tools include group calendars for managing group meetings, activities and milestones, group vaults for shared virtual property and group bank accounts for shared group funds.



Tools to change behaviour of objects created externally

- **Object:** col4m050.rwx
- **Description:** None
- **Action:** None
- **Owner:** 1150
- **Name:** danny kusuma
- **Built:** Sat Nov 1, 2003 7:53 PM

Immigration Officer: Welcome to the Virtual World hosted by the Faculty of Architecture, University of Sydney.

Download complete | Done | 0.0 K/sec | 29.8 frames/sec | 4:37:56 AM Mon Dec 18, 2006 VRT | 72 meters | 0.0 meters

Graphical cues to position objects

Tools to position objects created externally

FIG. 4. In-world design tools in (a) Active Worlds and (b) Kaneva for manipulating objects designed externally.

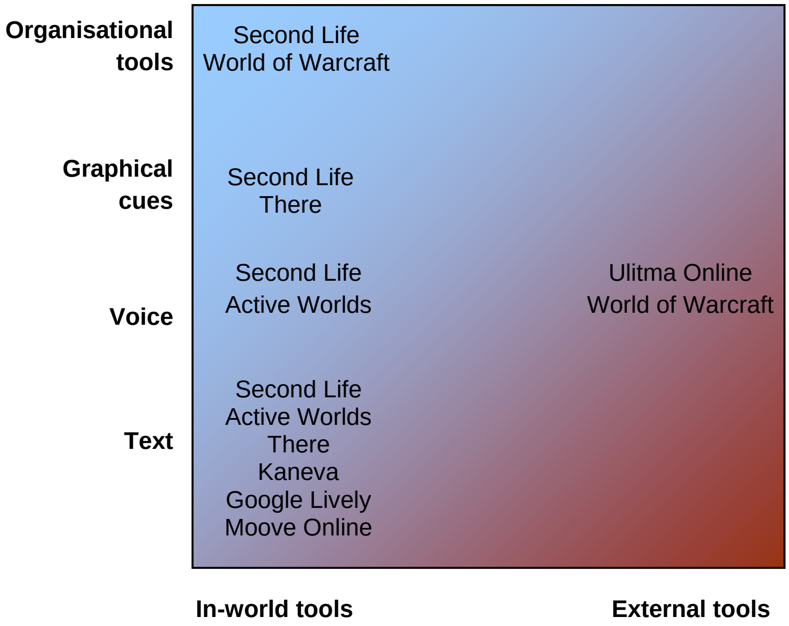


FIG. 5. Technology space for collaborative tools.

2.3.Artificial Intelligence

Virtual worlds generally provide avatars that are controlled by humans, enabling human-human communication and collaboration. However some virtual worlds (ActiveWorlds, 2007; Linden, 2009; There, 2009) also permit computer-controlled avatars called bots or agents. When bots are programmed with relevant cognitive process for creative design, they can proactively support and enhance human design. Different types of programmable agents are possible on different virtual world platforms. Tools for programming agent behaviours can be divided into four main categories, as shown in FIG. 6:

Function libraries are a short list of triggers and commands that may be performed by a virtual object. Triggers specify the condition that must be fulfilled for a command to be carried out. For example an object may rotate (command) when it is bumped (trigger). Several triggers and commands may be used together to achieve more complex behaviours.

Scripting languages define a syntax for programming world elements with complex sequences of commands. Scripting languages often incorporate a function library, but are more expressive than function libraries alone. For example they may allow the design of world elements that can make decisions or remember past events.

Application Programming Interfaces (APIs) are gateways through which external computer software can communicate with elements of a virtual world. External software can be written in an industrial strength programming language such as Java or C/C++. These languages are generally more powerful and expressive than scripting languages and can be connected to further third party tools such as databases or web pages.

Open source client software is a more recent means by which users can directly modify the virtual world. Designers can modify the world program itself, rather than just connecting their own external programs. This provides a powerful new tool for interaction design.

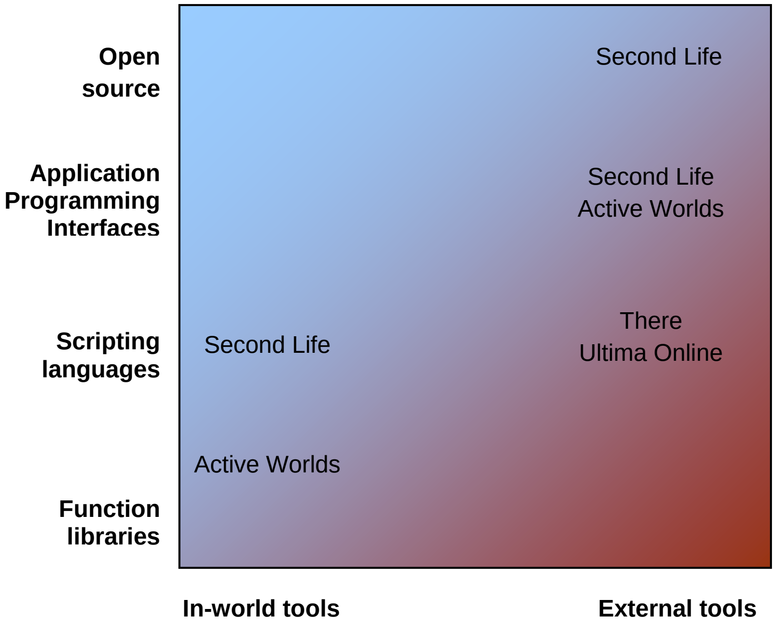


FIG. 6. Technology space for programming intelligent agents.

2.4.Summary

Virtual worlds are multi-faceted technologies with facets including their graphics technology, network structure, persistence, theme, communication tools, design tools, artificial intelligence, economy, user types and governance. The extent to which multiuser virtual worlds embrace all of these facets differentiates virtual worlds from computer-aided design (CAD) tools. The unique facets of virtual worlds permits their use in new ways for human-human collaboration and human-computer co-creativity. This section has examined three facets of virtual worlds in detail by defining technology spaces for each: design tools for modelling new artefacts, support for communication, and the ability to incorporate artificial models of cognitive design processes. This unique trio of design, communication and artificial intelligence is crucial for making virtual worlds useful as platforms for human-human collaboration and human-computer co-creativity. The support for collaborative creativity offered by multiuser virtual worlds forms a foundation for their support of design activities.

The technology spaces reveal that there is a trend towards the provision of more complex tools that permit more complex manipulation of virtual world content. This in turn increases the capacity of virtual world to host design activities. However, the technology spaces also show us that there are still gaps in the provision of internal tools. In addition the connections to external tools are sometimes weak and not always easy to use. The implications of these gaps and weak connections are further illustrated in the case studies in the next section.

3. VIRTUAL WORLDS IN DESIGN RESEARCH AND TEACHING

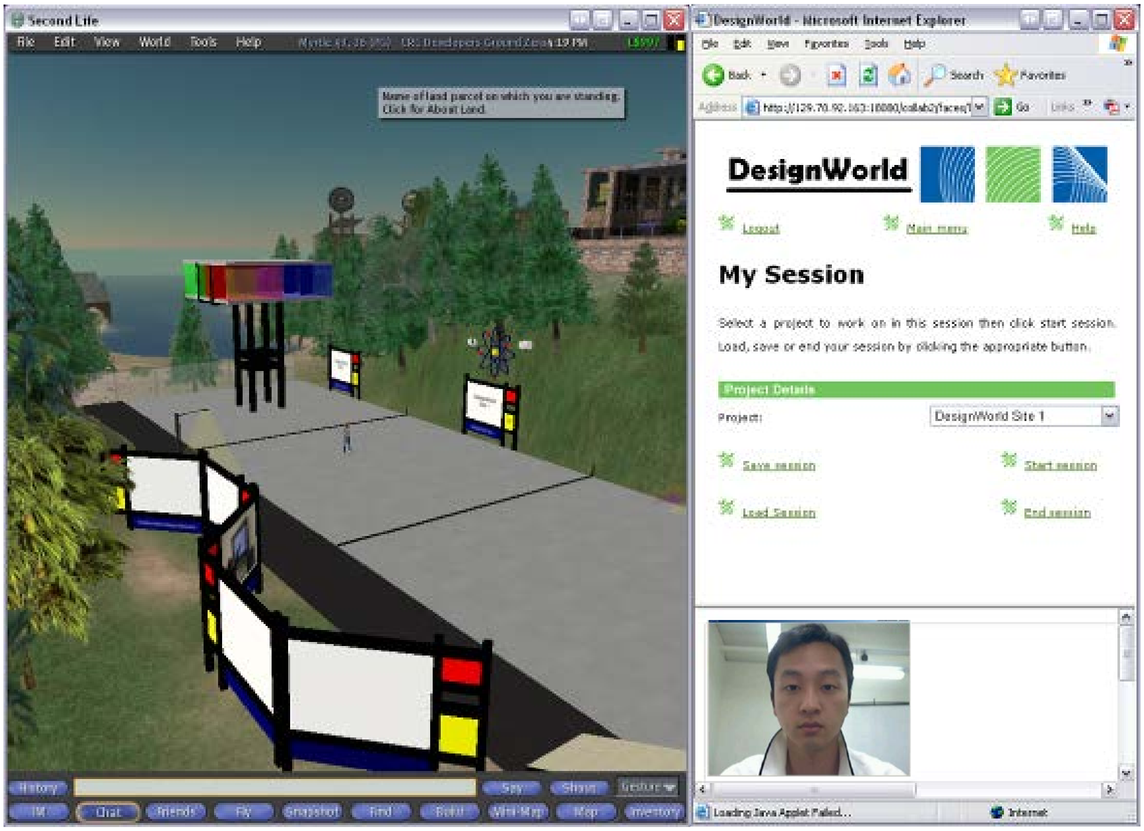
Virtual worlds such as *Second Life*, *Active Worlds, Kaneva* and *There* offer differing degrees of support for design, collaboration and artificial intelligence. The following sections discuss specific examples and identify the strengths and limitations of virtual world platforms for enabling and enhancing design by utilising the three technology spaces as discussed in Section 2. In particular, the case studies show how virtual worlds can support human-human collaboration and human-computer co-creativity.

3.1.Multidisciplinary Design for the AEC Domains

Collaboration is an integral part of the design process on most large-scale building projects. However, the complexity of building design leads to two conflicting requirements: the need for members of different disciplines to work on parts of the design using their own design models, and the need for members of different disciplines to synthesise and integrate their different design models into a single design representation (Rosenman et al., 2006). Virtual worlds offer a promising platform for multidisciplinary collaborative design because virtual world platforms are inherently multiuser, and do not impose a discipline-specific building model. This case study describes a project that built and evaluated a prototype design tool, called *DesignWorld*, based on virtual world software.

DesignWorld is an augmented virtual world platform based on *Second Life* for multidisciplinary collaborative design. Early prototypes for this project were developed in *Active Worlds.* However, the lack of support for in-world 3D modelling design inspired the transition to an alternative platform. The virtual world *There* also proved difficult to use for this type of research due to a delayed object upload process whereby new objects are reviewed by *There* staff for suitability before being permitted in-world (There, 2009).

The final *DesignWorld* prototype, shown in FIG. 7, was developed in *Second Life*. Existing in-world tools for object creation and manipulation are augmented with web-based, design-specific tools for sketching and managing discipline specific views and relationships.



Name of land parcel on which you are standing.
Click for About Land.

Select a project to work on in this session then click start session. Load, save or end your session by clicking the appropriate button.

Project: DesignWorld Site 1

Loading Java Applet Failed...

FIG. 7. A prototype system for multidisciplinary collaborative design. The Second Life virtual world supports 3D design for building projects. Second Life is augmented with web-based design tools for 2D sketching and collaboration. Image from et al., 2006).

Artificial agents were used to manage the communication of data between the web-based tools and the virtual world. In this project, reflex agents were used to relay user commands. However the use of the agent model permits future exploration of autonomous agents that can themselves contribute to the design process, permitting human-computer co-creativity in addition to human-human collaboration. The agents were implemented using a combination of *Second Life's* built in scripting language (LSL) and communication with custom external software written in the Java programming language.

DesignWorld also makes use of synchronous communication and collaboration via text. This was augmented with voice and video externally via the web.

Protocol studies of designers using *DesignWorld* showed that designers were able to effectively collaborate on defining a design concept and developing a 3D model of their design artefact (Gul & Maher, 2006). In particular, the 3D virtual world supported the designers while collaboratively developing and refining 2D sketches and a 3D model comprising multiple objects. It provided a visual analysis of designers' own design ideas in coordination with their partner's design contributions.

The main limitations of the virtual world in this case were the lack of voice communication and the difficulty of programming complex artificial agents using the built-in scripting language. Since this project was completed, *Second Life* now incorporates voice communication. However, the scripting language and facility for communication with external, industry strength programming languages remain an area for further work. The scripting language is relatively limited in its expressive power and communication with custom external software is very slow due to server-side delays instituted for security purposes.

3.2.Intelligent Environments

Research work in the area of Intelligent Environments aims to design places that can adapt, respond to, support and enhance human activities. The majority of existing intelligent environment research has focused on the design of system architectures to manage communication between hardware devices and sensors (Brooks et al., 1997; Coen et al., 1999) in physical spaces. However, virtual worlds make it possible to extend this work in a number of ways. This case study reveals a number of possibilities.

Firstly, by taking intelligent environment research into virtual spaces, it becomes possible to experiment with complex artificial intelligence techniques without the need to build complex communication architectures. FIG.8 shows a meeting room in *Second Life* that mirrors a physical meeting room in a real-world university. The virtual meeting room is fitted with sensor and actuator scripts that can monitor and control the lights, smart boards, chairs and projector screen. The room has an embedded curious agent that uses a computational model of curiosity to identify interesting actions by avatars and a computational model of learning to learn how to copy those actions. Over time, the room learns to perform tasks such as turning the lights on and off and activating the smart board on behalf of its inhabitants (Merrick et al., 2008).

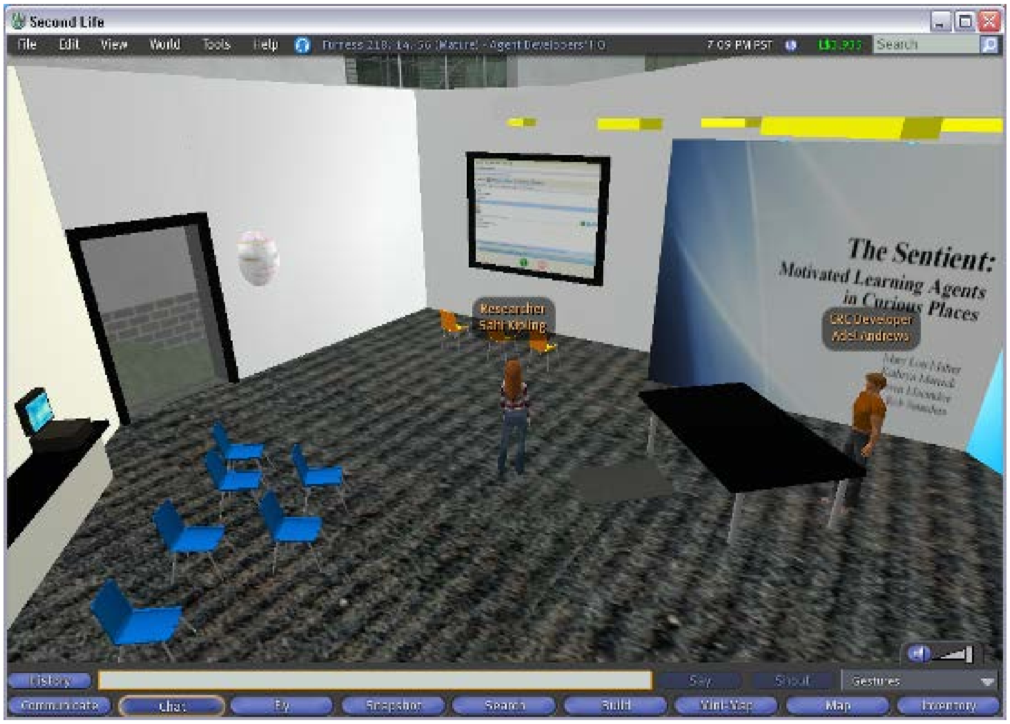


FIG.8. The Virtual Sentient: An intelligent virtual meeting room and lecture theatre. Image from (Maher et al., 2008).

This project made use of *Second Life's* in-world scripting language (LSL) for implementing the intelligent design agents that control the behaviours of the meeting room. The LSL sensor and detection functions permit programming of design agents that can monitor their surroundings, reason about the sensed data and modify their environment. From a design cognition perspective, the key limitations of this approach are the limited sensory radius of scripts and the limited script memory. Real-world designs are generally complex, comprising many objects and devices that may be monitored, remembered or controlled by design agents. The limited script sensory radius and memory limits the complexity of intelligent environment simulations that can be undertaken in virtual worlds, although it is envisaged that this will improve in future.

The second extension to intelligent environments made possible by virtual worlds is the idea of adaptive virtual environments as functional spaces in their own right. For example, in design related industries virtual worlds can be used for meetings or collaborative design when individuals are not physically co-located. Virtual worlds also permit human-human collaboration and communication over long distances in other industries, including entertainment (Blizzard, 2009; ElectronicArts, 2009), business (Coca-Cola, 2007), charity work (American-Cancer-Society, 2008), defence applications (Bohemia-Interactive, 2009) and education (Gu et al., 2009).

3.3.Interactive Design in Virtual Worlds

We have also explored the capacity of virtual worlds to support novel human-computer interaction in a number of design teaching scenarios. This case study and the next, discuss the use of *Second Life and Active Worlds* in university level design computing courses.

FIG. 9 shows images from students' designs in an assignment titled *Impossible Places* from Semester 2, 2007. Students designed personal spaces that would be impossible in the real world, while practicing the use of navigational principles and developing a sense of place and aesthetics relevant to virtual worlds. The solutions presented by students demonstrate the capacity of virtual worlds to support functional places that would not be possible in the real world. These spaces include a personal space (FIG. 9(a)), a museum (FIG. 9(b)) and a shop (FIG.

9(b)). Virtual museums provide a hub for education, permitting people to access virtual representations of material that they may not otherwise be able to visit. Likewise, virtual shopfronts can open up a global market for businesses without the need for expensive real-world infrastructure. These virtual places support real-world industries by offering a novel human-computer interactive experience that goes beyond traditional 2D websites. 3D virtual worlds offer a sense of place and presence that is different to traditional websites.

This project used the *Second Life* virtual world. This assignment made use of the two types of design tools: in-world tools for designing with primitive 3D shapes and facilities for importing objects designed using third party software such as Maya. The in-world modelling facility of Second Life encourages students to experiment and generate unique models quickly. The facility for using third-party software, while still somewhat experimental, allows design computing and digital media students to draw on their existing skill sets to design complex virtual places. The in-world design tools provide an advantage over worlds such as *Active Worlds* and *There* in which customised models must be made outside the world and uploaded. This limits the capacity for collaboration on such models.

FIG. 10 shows images from a group assignment titled *You Versus the World*. Like the *DesignWorld* research, this assignment combines in-world collaboration with design and basic concepts in artificial intelligence. Students designed games in which the primary antagonist was a dynamic built environment. No humanoid or animal characters were permitted. As well as complementing research in intelligent, adaptive environments, this assignment explored a new paradigm for games in which the built environment is dynamic and responsive. This exploratory work again demonstrates how virtual worlds can serve as a basis for novel human-computer interactions.

One issue in using *Second Life* is that LSL can be difficult for designers, who often come from a non-computing background, to master. In previous years, students using *Active Worlds* could draw on the library of simple, pre-defined scripts for common interactions such as opening a web page, teleporting avatars or creating an object animation. This was overcome to some extent by organising students into cross disciplinary project groups so they could utilise each others skill sets.

FIG. 9. Impossible Places. Students designed personal spaces that combine elements of real world design with concepts that would be impossible in the real world. (a) Tree House (b) Floating Space Museum (left) and Free Shopping (right). These virtual places offering a novel human-computer interactive experience that goes beyond traditional 2D websites.

FIG. 10. You Versus the World. Students built games in which the primary antagonist is the environment. (a) Ziggurat: Players navigate challenges inside a ziggurat (b) Clock Game: Players navigate challenges inside a clock. This explores a new paradigm for games in which the built environment is dynamic and responsive.

This assignment also made use of the collaborative design capacity of virtual worlds using object permissions. In *Second Life*, the ownership of the objects can be flexibly arranged and shared, but one object can only be manipulated by one user at a time. This feature of the 3D modelling environment encourages designers to work individually on separate parts of the design model during collaboration. This can be both a strength and limitation depending on the needs of a particular design team.

In *Active Worlds*, designers may only manipulate the properties of their own objects. As a result, during a group project, it was observed that a structured task division was required for collaboration. This means that students have to determine the overall concept of the design and separate the parts to construct the model in order to work collaboratively.

3.4.Collaborative Design in Virtual Worlds

We have also explored the capacity of virtual worlds to support collaborative design in a number of design teaching scenarios. This case study, discusses the use of *Second Life* in university level design, teamwork and students' perceptions on the application.

This case study aims to understand the fundamental difference between the nature and characteristics of collaborative design in real and virtual worlds and how the different scales of the proposed designs lead to differences in collaborative design in both real and virtual worlds. More specifically, this case study explores the impact of large-scale and small-scale designs in both virtual worlds and the real world. In general, face-to-face communication in the real world has been the most common way that designers communicate in collaborative design. Designers traditionally communicate their concepts and strategies with different media, such as drawings and 3D physical models. Virtual worlds provide a new platform for designers to develop and communicate their designs as interactive places.

The design collaboration involved in the project was implemented between two countries, the first country comprising thirty people and the second thirteen people. Each group carried out designs in four design sessions with each lasting 30 minute as follows:

Session 1 – Synchronous design collaboration in the real world for large-scale design: A design studio is the design task. This design studio includes different rooms for each member (as private spaces) and a multi-function room for meeting and entertainment (as a public space). The design studio should be designed for the real world. Members can decide the shape, size and colour of each private space. The public space is then designed by all the members.

Session 2 – Synchronous design collaboration in the real world for small-scale design: A workstation specifically for the design studio above is the design task. This workstation includes different specific requirements and a universal function for each member. This workstation should be designed in the real world and is placed in the design studio. Members work together for the shape, size and colour for the workstation.

Session 3 – Synchronous design collaboration in the virtual world for large-scale design: A design studio is designed in *Second Life* with same design requirements as in Session 1.

Session 4 – Synchronous design collaboration in the virtual world for small-scale design: A workstation is designed in *Second Life* with same design requirements as in Session 2.

For the four sessions, participants performed a protocol analysis to investigate the differences in the aspects of social interactions among design team members, awareness and presence in design processes, tool applications in design processes, the function, behaviour and structure of each design, and the level of support for design creativity. FIG. 11(a) and FIG. 11(b) show examples for a design studio and a workstation inside it respectively.

FIG. 11. (a) An example of the large scale design (a design studio) in Second Life. (b) An example of the small scale design (a workstation) in Second Life.

Most of the participants commented that while designing in the real world, there were small variations in social interactions, awareness of design processes and the level of support for design creativity between large and small-scale designs. However, they also commented that while designing in *Second Life*, there were large variations between large and small scale design, which means that the scale does matter to the performance of collaborative design in virtual worlds. Participants found that it was more difficult to conduct the large-scale design (a studio layout) than the small-scale design (workstation furniture). This was partially due to the difficulty of communicating between avatars located far apart. Participants found that standing around the peripheral of the studio land was more difficult than standing with all the avatars gathered together around a small-sized workstation. While gathering around a workstation, avatars could easily find and face the person they wanted to talk to. Being together also increased the awareness of others' activities and social presence.

In the large-scale design, avatars could choose to gather together for a short common discussion, but participants commented that they preferred to stand in different parts of the studio because of their different roles in the design work. In this case, moving around to reach a particular person was difficult and time consuming. This situation is quite similar to the real world where physically being with someone typically results in the highest level of awareness and presence. The experiment thus demonstrates the capacity of virtual worlds to support human-human collaborative design.

3.5.Summary

Current virtual worlds such as *Second Life, Active Worlds*, *Kaneva* and *There* offer differing degrees of support for design, collaboration and artificial intelligence. The case studies above demonstrate that recent virtual world platforms offer support for in-world, open-ended modelling, improving the capacity of these platforms to support design. Likewise, recent virtual worlds have improved the feed-through and consequential communication capacity of virtual worlds, thus improving their ability to support multidisciplinary collaborative design. Improvements in scripting tools have permitted some enhanced support for agent-based design cognition research, although this remains an area for further development.

The case studies above have illustrated that the unique technology facets of virtual worlds permit us to push the boundaries of computer-aided design from individual design to collaborative team design and from human-only creativity to human-computer co-creativity. With the growing popularity of virtual worlds, and their increasing ability to support large social networks and communities, it seems that yet another step may be possible in the near future. This step could take design from the hands of small, expert teams to large, mixed-skill collectives by harnessing the power of mass participation to achieve collective intelligence in design. This is discussed further in the next section.

4. FUTURE DIRECTIONS AND CONCLUSION

Predicted advances in cyberworld platforms, including both virtual worlds and social networking sites, have the potential to further support and advance design computing and cognition research and teaching. This section considers these advances in three sections: technological advances, collaborative advances and educational advances. A clear understanding of the facets of virtual worlds and cyberworlds will be critical for harnessing these technologies effectively for design.

4.1.Advancing Technologies for Open-Ended Modification of Virtual Worlds

FIG. 12 summarises the technology facets for future development of virtual worlds for design, as they have been discussed in the body of this paper. Two main areas for development are visible: improvements to in-world tools for 3D modelling and improvement of in-world tools for behaviour programming. Faster, more expressive programming environments for example, will permit further design cognition research through simulations of more complex cognitive models. This will advance research in human-computer co-creativity by permitting human-controlled avatars to interact with advanced computer-controlled avatars in design scenarios.

More expressive programming environments will also permit research with more complex, dynamic and intelligent virtual environments. This may include generative design of virtual worlds and adaptive world designs, which will extend the economic viability of virtual worlds to new functions. The primary applications of existing virtual worlds are games and social interaction. New technologies that support the application of design knowledge to the development of virtual worlds will permit us to better align the design of virtual worlds with the key activities that are required by real-world communities, such as those for commerce, retail, banking, healthcare, education and others.

In another example, greater access to client side and server side source code will open the way for design research that explores the boundaries between virtual and physical worlds. Current designs of virtual worlds are largely influenced by the physical world. Limited by our traditional perceptions of built environments, the design principles and the full design capabilities of virtual worlds – such as being dynamic and adaptive – have not yet been thoroughly explored. Advances in virtual world technologies will permit us to explore the boundaries between the physical and the virtual. Examples include connecting avatar actions to novel hardware devices to permits users to interact with the digital world using whole-body movements in the physical world.

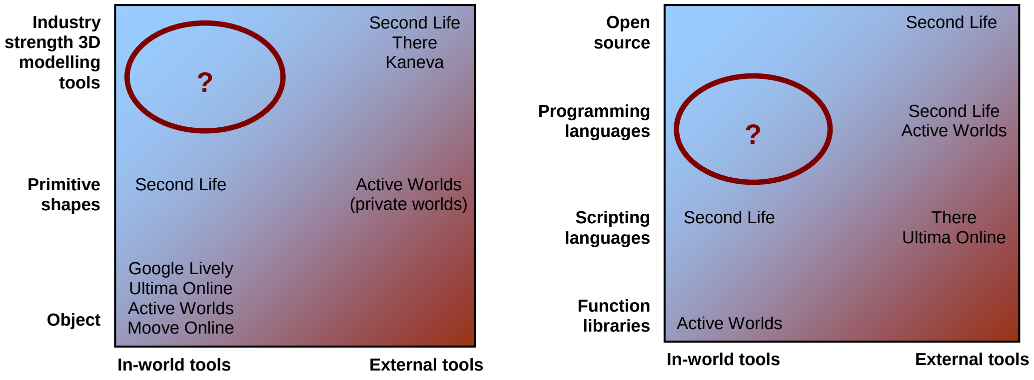


FIG. 12. Future directions for design tools (left) and behaviour programming tools (right).

4.2.Advancing Technologies for Mass Participation in Virtual Worlds and Cyberworlds

Cyberworlds, including both virtual worlds and social networking sites are an emerging technological phenomenon that has seen unprecedented growth in the last five years. Social networking sites in particular are among the most visited websites globally, with sites such as *Facebook* boasting over 500 million active subscribers in 2010 (Facebook, 2010). Cyberworlds are also recognised as a platform for collective intelligence (Levy, 1997), a form of group intelligence that emerges from collaboration and competition among large numbers of individuals. Collective intelligence games such as *I Love Bees* (McGonigal, 2008), and applications such as NASA’s *Clickworkers* (Romero, 2009), have demonstrated the capacity of collective intelligence to solve complex problems. Because of the close relationship between design and cyberworld technologies such as 3D virtual worlds, there appears a strong possibility of also harnessing collective intelligence for design tasks (Maher et al., 2010).

To achieve collective intelligence in design, an understanding is required both of which facets of existing cyberworld technologies are necessary both to foster collective intelligence and to support design. Further investigation of facets of virtual worlds beyond those studied in this paper will be required, including their economy, user types and governance. Our technology spaces provide a basis for this investigation by providing a way to identify gaps and challenges in existing technologies. On the issue of governance, for example, one of the challenges for harnessing virtual worlds for collaborative design on any scale is avoiding the computer security problems that arise with online computing. These include malicious activities that steal or damage data or damage the reputation of the online organisation. These sorts of activities need to be effectively neutralised to permit safe, wide-scale use of virtual worlds in design collaboration.

4.3.Advances in Educational Technologies for Design

Finally, regarding the prospect of widely adopting multiuser virtual worlds in design and design education, our experience shows that multiuser virtual worlds have exhibited significant potential, providing designers and students with opportunities to explore advanced design computing and cognition issues, as well as experiencing collaborative design and learning. Nevertheless, these new design and learning environments also impose challenges on designers, students and academics alike. Participants need to develop new, often cross disciplinary skill sets to use virtual worlds effectively, including a combination of computing, design and communication skills.

4.4.Conclusion

This paper investigates the innovative use of emerging multiuser virtual world technologies for supporting human-human collaboration and human-computer co-creativity in design. It defines three conceptual technology spaces describing the different aspects of virtual worlds that make them useful as platforms for design: design tools for modelling new artefacts, support for communication, and the ability to incorporate artificial models of cognitive design processes. Four case studies were conducted and examined in terms these aspects using multiuser virtual worlds. Analysis of these case studies reveals the following advantages of virtual worlds as one of the important platforms to support design:

- They permit the synthesis of design computing technologies, collaborative design and artificial models of cognitive design processes;
- They support human-human interaction, potentially on a very large scale;
- They support human-computer interaction;
- They can be used to simulate and experiment with new designs and design related systems;
- They can be functional places in their own right.

In the long term, it is envisaged that advances in virtual world platforms will permit virtual worlds to support new kinds of applications of design computing and cognition through the integration of human-human and human-agent interaction. These may extend to entertainment, social interaction, commerce, health, defence and education.

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