

Chapter 2

Background

The background chapter reviews three areas that are closely related to the development of the Generative Design Agent (GDA) model and the generative design grammar framework. These are designing virtual worlds, agent models and shape grammars. Section 2.1 briefly introduces the history and general design issues of virtual worlds. Section 2.2 presents our observation on the stylistic characterisations of virtual worlds. In section 2.3 the first half discusses agent models and their applications in general. The rest of section 2.3 looks at an agent model for 3D virtual worlds in particular. Finally, section 2.4 reviews shape grammars and their applications for designs.

2.1 DESIGNING VIRTUAL WORLDS

The GDA model and the generative design grammar framework are developed for the purpose of dynamic designs of virtual worlds. A literature review on the topics of designing virtual worlds is useful for this study.

2.1.1 Concepts of Virtual Worlds

In this thesis the term virtual world, or virtual architecture, virtual environments, cyberspace, virtual places, information space and so on, refers to networked environments that are designed using the metaphor of architecture. These networked environments are capable of supporting various activities online; for example, social communication, internet gaming, virtual learning, design collaboration, e-commerce and many others. This definition highlights two key issues when designing virtual worlds: activities and metaphors. Firstly, virtual worlds are designed for certain purposes and support various activities online. Secondly, virtual worlds are designed using the metaphor of architecture. The use of the metaphor provides a consistent and familiar base for designing virtual worlds, and for virtual world occupants to interact with the designed environments and with each other.

The common features that distinguish virtual worlds are very well summarised by Singhal and Zyda (1999). A virtual world is a software system where multiple users connect from different geographical locations and interact with each other in real-time. Virtual worlds can be characterised by five common features: a shared sense of location, a shared sense of presence, a shared sense of time, online communication, and interaction with the virtual environments. Highlighted by these features, virtual worlds provide multiple users with the ability to interact with each other, to share information, and to interact with the virtual environments by manipulating virtual world objects in the environments through immersive computer graphics. Singhal and Zyda also draw the differences between virtual worlds and other existing networked environments or tools.

- The ability to support multiple users differentiates virtual worlds from standard virtual reality and game engines.

- The ability to share and manipulate virtual world objects differentiates virtual worlds from traditional chat rooms.
- The ability to support real-time interactions differentiates virtual worlds from email and traditional web browsing.

However, despite the above definitions and characterisations there is really no universal definition or standard form of virtual worlds. Virtual worlds as a research and design topic is a relatively new emergent area, which still requires much understanding. The potential of virtual worlds has yet to be further explored.

2.1.2 History of Virtual Worlds

The brief history of virtual worlds can be traced back to about two decades. The term “cyberspace” was first introduced in the science fiction novel *Neuromancer* (Gibson 1984). In this novel, Gibson describes cyberspace as “a consensual hallucination experienced daily by billions of legitimate operators, in every nation.... a graphical representation of data abstracted from the banks of every computer in the human system... lines of light ranged in the nonspace of the mind, clusters and constellations of data. Like city lights...” The main contribution of Gibson’s novel, as describe by Whittaker (2004), is that it gives “expression to the emerging technologies” at the time, such as personal computers, the internet, computer graphics, virtual reality and other digital information. Thereafter, especially in the 90s, the term “cyberspace” attracted the attention of the general public, and became extremely popular and influential among researchers and practitioners in different areas. To a certain extent, cyberspace seems to have become an express tunnel that links together the present and future and which provides a new horizon for innovation, imagination and opportunities. It has also had an impact on areas like architecture, education, social science, business and so on. This newly emergent area does not develop alone. It includes many sub-areas, such as design representation, human computer interaction, artificial intelligence, computer graphics, virtual reality and networked technologies.

The development of virtual worlds can be roughly categorised to have taken two major directions: the conceptual development of virtual worlds, and virtual world design and implementation. In the conceptual development of virtual worlds, researchers and design practitioners explore the possibilities of virtual worlds, illustrate the future of virtual worlds, and study the impact of virtual worlds on existing design theories and practices. For example, Benedikt (1991) collects a series of influential writings by academics, designers, artists, novelists, engineers and businessmen to predict and illustrate the future of cyberspace from different perspectives where everything seems possible. These writings also outline the dramatic changes in the physical world and our future daily life due to the influence of cyberspace. Woolley (1993) discusses the emergence of virtual worlds, which changes public reality through virtual reality and artificial reality. Anders (1998) presents theories and examples which use space as a cognitive tool for managing our daily activities in the physical world, and how these concepts may be extended to cyberspace. Wertheim (1999) follows the history of the western conception of space from the middle ages to the information ages, and critically accesses the cyberspace and cyber culture. Now in the 21st century, when we look back and re-examine some of the concepts and predictions, virtual worlds are indeed challenging and gradually changing the traditional forms of communication, education, entertainment, business and so on. The physical world, however, has not been radically overtaken by the emergence of virtual worlds as some have predicted. Virtual worlds co-exist with the physical world and supplement the physical world.

In the direction of virtual world design and implementation, researchers and design practitioners work on the technical realisation of virtual worlds. The early forms of virtual worlds emerged in the early 90s, when the World Wide Web became more accessible. The origin of virtual worlds has served two purposes:

- Military simulation; for example, SIMNET (simulator networking) developed by the US

Department of Defense that simulates battlefields for military training purposes.

- Networked games; for example, DOOM, a 3D networked game released by id Software¹, downloaded and shared by millions.

Beyond its origin, virtual world design and implementation have been enriched and diverted to take on various forms for different purposes. The internet has accommodated many different technologies supporting the early text-based virtual worlds, graphical virtual worlds and 3D virtual worlds. The purposes that virtual worlds serve have expanded to include social communication, education, design collaboration, e-commerce, and so on. The literature on virtual world design and implementation, according to Maher (1999), can address one or more of the following:

- Implementation: technologies for realising virtual worlds.
- Representation: a consideration of the underlying system for representing various components of virtual worlds.
- Interface: the types of interface provided to people for accessing virtual worlds, interacting with the environments, and interacting with each other.

At the implementation level, 3D models have become the dominant form for visualising virtual worlds nowadays following some early attempts at using text-based and graphic representations. The introduction of the Virtual Reality Markup Language (VRML) in 1994 led to the first 3D web browser. VR technologies, which had been used for simulation, then became the main means for realising virtual worlds (Morgan and Zampi, 1995). This marks the beginning of the 3D era for virtual worlds.

At the representation level, the main research question concerns the use of metaphors. For example, Cicognani and Maher (1998) study how text-based virtual worlds, mainly MOOs, are represented and designed. Maher et al (2001, 2000 and 1999) extend the study from the linguistic characterisations to include graphical and spatial characterisations. Using the architectural metaphor, the latter study draws an analogy to the built environment, and a coherent hierarchy of architectural elements, such as buildings, rooms and objects are developed for representing object-oriented virtual worlds. More recently, agent models have been used for representing virtual worlds (Maher et al 2004, Smith et al 2003 Maher and Gero, 2002) in order to integrate artificial intelligence to virtual worlds.

At the interface level, the input and output devices of virtual worlds are explored. The area of ubiquitous computing has provided much insight for the future development of this area. However, the most common interface nowadays for accessing virtual worlds is still via the use of a personal computer screen, keyboard and mouse.

2.1.3 Design Metaphors

Through the use of metaphor, concepts in one domain are understood, expressed and experienced in terms of another (Lakoff and Johnson 1980). The early use of metaphors can be seen in ancient literatures, and have been widely applied and recognised in poetry and novels. Metaphors are not simply about language; in fact, human conceptual system is largely metaphorical (Erickson 1990, MacCormac 1985, Lakoff and Johnson 1980). In other words, the use of metaphors shapes human understanding, thus greatly affects how we think and what we do. The essence of metaphors is very well highlighted by MacCormac (1985): “without metaphors, to describe and explain the unknown would become impossible”. This is especially evident in the modern period with the rapid development of new technologies, which appear to have been unknown to us initially. Therefore, we extend familiar concepts to understand, apply and further develop these new

¹ <http://www.idsoftware.com>

technologies. There are many examples of these kinds in our daily life; for example, telegraph, television, digital television, email, e-commerce, e-learning and so on. Lakoff & Johnson (1980) highlight the power of metaphors below.

- Metaphors pervade the human conceptual system. The use of metaphors enables us to grasp many concepts that are either abstract or not clearly delineated in our experiences. It is by means of other concepts that we better understand, in terms of familiar structure, spatial orientation, objects, and so on.
- Metaphors define reality, especially social realities, by providing a coherent network of entailments that highlight certain aspects of our experiences but hide others. The acceptance of the metaphor forces us to focus only on those highlighted aspects of our experiences, and leads us to believe that the entailments of the metaphor are true. The created reality can then be used as guidance for future actions, and these actions, in turn, reinforce the power of metaphors to make experiences more coherent.
- Metaphors can provide new meaning. Unlike conventional metaphors that structure the general conceptual system of our culture, new metaphors are imaginative and creative and exist outside the conventional conceptual system. Such metaphors are capable of giving us a new understanding of our experience.

In the design domain, the use of metaphors allows researchers and practitioners to adopt familiar design concepts to make references to other design knowledge, or to simply be inspired. Different metaphors have been applied to compose music, create artworks, design artefacts and generate systems in areas from music and fine art to architecture, engineering, computer science and so on. For example, in photography, Radice (1988) documents a series of pictures by the Italian designer and photographer Ettore Sottsass taken between 1972 and 1973. These pictures are largely comprised of artificial objects with the natural desert surroundings of Spain. Each artificial object was carefully selected and placed in the scene. These objects went beyond their original meaning in industrial civilisation, and were used as metaphors by the artist which he illustrated by the interplay with the natural landscape. For example, a door does not simply define a gateway to exit one place and enter another; instead, through the door we “enter into darkness” or “are meeting our love”. In computer science, the use of metaphors is also very common. Since the nature of our conceptual system is metaphorical, it is not difficult to understand that the use of appropriate metaphors plays an important part in assisting our interactions with the environments we inhabit. This is also the case when we interact with computer environments (Hsu and Schwen 2003, Marcus 1998, Erickson 1990). Stefik (1996) provides a historical review of the metaphors we use to describe and design computers and computer networks:

- Giant brains: the main metaphor applied to computers in the 50s was the giant brain. This misleading metaphor failed to predict the future of computers. Computers did not become bigger in order to become more powerful.
- Information superhighway: in the 80s, the information superhighway metaphor was applied to describe the high-speed connectivity of the computer networks. This metaphor is useful for thinking about the flow of information, but does not provide adequate insight for illustrating how our future lives would be affected by computers.
- Multiple metaphors: Stefik present the multiple metaphors to extend and enrich the concept of the information superhighway by thinking about emerging information infrastructure and exploring new possibilities. Stefik explores four of these multiple metaphors: digital library (for thinking about information storage and shared knowledge), electronic mail (for thinking about digital communication), electronic marketplace (for thinking about digital properties and commerce), and digital worlds (for thinking about virtual community and its supports like virtual reality, telepresence and so on). Each

metaphor addresses one particular aspect, which together provide a richer range of meanings and possibilities for the information superhighway.

From these multiple metaphors, it is evident that a close link has been drawn which refers to various familiar concepts in the physical world. Similarly, to further extend these ideas, we can consider designing virtual worlds in terms of designing built environments. This leads to the use of the architectural metaphor for designing virtual worlds.

2.1.4 Place Making in Virtual Worlds

The image of architecture has always been defined and perceived as the art of places. In the physical world, places differ from spaces by including social and cultural values, besides spatial configurations (Kalay 2004). This definition of place nicely highlights the key elements in the formation of places. They are the spatial environment, people who inhabit the environment and the interactions between these two. This understanding is echoed by many other scholars. Norberg-Schulz (2000) uses the word “totality” to describe the art of places, which by principle deals with “the experience of living”. Steele (1981) illustrates a diagram to define the concept of a sense of place: “Setting + Persons = Sense of Place”. The term “setting” in the diagram refers to the “surrounding” (spatial setting) and “context” (social setting). The persons are psychological factors. Relph (1976) claims that places at all scales are “whole entities” that synthesise natural and artificial objects, functions and activities, and meanings given by intentions.

By using the metaphor of architecture we design virtual worlds by place making rather than by page and document making. The underlying rationale of using the architectural metaphor is based on an assumption (Kalay, 2004, Champion and Dave, 2002, Kalay and Marx 2001) that, because to a large extent our social and cultural behaviours are organised around spatial elements of the physical world, we can carry over these patterns of behaviours to virtual worlds by designing them to have the same potentials for conception and interaction that the physical world exhibits. The patterns of behaviour we learn in the physical world therefore become useful in virtual worlds. By structuring virtual worlds in a way that allows us to apply these learned traits from the physical world, we can reduce the cognitive efforts needed to inhabit the worlds.

Adopting the metaphor of architecture, designing virtual worlds as a relatively new area is able to make analogical references to architectural design which has been developed for centuries, rich with its own theories and practice. The analogy provides a base to understand and further extend the use of these networked environments. On the other hand, the emergence of virtual worlds also has had a reverse impact and created new dimensions for exploring architectural design. Such examples include hyper architecture (Puglisi 1999), information architecture (Schmitt 1999), liquid architecture (Novak 1991) and so on.

However, place making in virtual worlds is, after all, different from place making in the physical world. Firstly, virtual worlds are networked environments. Virtual worlds can be experienced only via computers. Secondly, designing virtual worlds can go beyond the principles of architectural design to further explore the potentials of the virtual worlds, as these worlds do not need to obey the law of physics and besides input and output devices, comprise pure computing entities. With these considerations in mind, designing virtual worlds, therefore, is not authentic place making; rather, it is a loose sense of place making that adopts certain relevant design concepts and knowledge from built environments for the virtual context. Based on Kalay’s criteria for virtual place making (2004), we summarise the following characteristics of place making in virtual worlds:

- Functional virtual places: places provide ambient environments for certain intended activities online, which offers the reason or purpose for being there.
- A sense of location: places provide relative locations, and locations create a context for the intended activities to occur. A sense of location helps to recall our traces in the virtual worlds, and these traces help us to differentiate one place from another.

- A sense of presence: places involve some kinds of engagement with objects and people. Through these interactions, a sense of presence is provided.
- Uniqueness of virtual places: virtual worlds afford a variety of experiences different from our physical experiences; for example, virtual worlds have unique ways of transportation from place to place using hyperlinks.

2.1.5 Virtual Worlds Design Platforms and Examples

There are far fewer examples of designed virtual worlds compared to architectural examples in the physical world. This is reasonable since virtual worlds only emerged about two decades ago. During the rather brief history of virtual worlds, design tools and technologies for designing virtual worlds have been through a cycle of evolutionary changes from the early text-based MUDs and MOOs to the current 3D virtual worlds.

In the text-based virtual worlds, as shown in Figure 2.1, words are the only matter because the creation of the worlds depends almost exclusively on the use of words. The virtual worlds and their components are described using texts. People connect to a shared networked environment to interact with the environment and each other by using text commands. MUDs, which stand for Multi-User Domains, are widely recognised as the first generation of shared networked environments. It was developed as a place for the role playing the game Dungeon and Dragon.

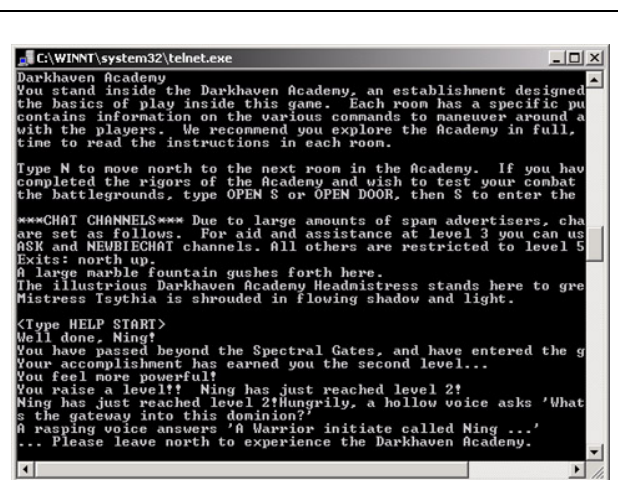


Figure 2.1. A MUD Example: 7th Circle².

In 1990, Stephen White developed the first MOO server. MOO stands for MUD, Object-Oriented. MOO enables an easier creation of virtual worlds through object-oriented programming³. The use of object-oriented programming for designing virtual worlds is influential, as most of the current virtual worlds are object-oriented. Subsequent development of MOOs adds a graphical dimension to the virtual worlds by using a web browser window for displaying the worlds. As shown in Figure 2.2, each MOO object is visualised with a graphical icon in the worlds.



Figure 2.2. A MOO example with a graphical interface: Tappedin⁴.

² telnet://mud.oro.net:4000

³ Refer to MOO-Cows FAQ for more detail: <http://www.moo.mud.org/moo-faq>

⁴ <http://tappedin.org>

In text-based virtual worlds, occupants rely largely on imagination to perceive and process spatial information of the virtual worlds. In graphical virtual worlds, the text descriptions are enhanced by the use of images which provide virtual worlds with a new graphical dimension. However, 2D images do not really allow us to fully exploit the spatial organisation of the worlds. After these early attempts, it seemed quite natural to search for 3D alternatives to develop virtual worlds that could mimic the physical world and provide spatial experiences familiar to us.

Nowadays, most virtual worlds are visualised using 3D models. Platforms for designing 3D virtual worlds include Active Worlds⁵, Blaxxun Platform⁶, Second life⁷, Croquet⁸, Virtools⁹, and others that have been developed from gaming engines such as Quake¹⁰. The development of 3D models as virtual worlds is a major focus for most of the design platforms. This focus leads to a strong emphasis on the visual aspect of the designs. In these virtual worlds, due to the use of the architectural metaphor, virtual world objects appear as architectural or architecture-like models in the virtual worlds. Selected virtual world objects can have event-driven behaviours in the worlds to support predefined actions. Virtual world occupants are represented as avatars, the animated characters, in the worlds. The occupants communicate with each other via online communication and interact with the environments by activating behaviours of relevant virtual world objects. In the remaining section we briefly review several platforms that are currently available for designing 3D virtual worlds which support these typical features.

Using Active Worlds (AW), virtual worlds are designed and implemented based on the AW object library. The object library provides a list of 3D models that simulate architectural or architecture-like elements. Occupants are able to build in the worlds using these models. The object library can be expanded by using external 3D modeling and translation tools. Virtual world objects can have behaviors by using AW triggers and commands, a kind of scripting language supported by AW. The interactions in AW can be extended using the software development kit (SDK). Figure 2.3 shows a virtual cinema designed and implemented using AW.

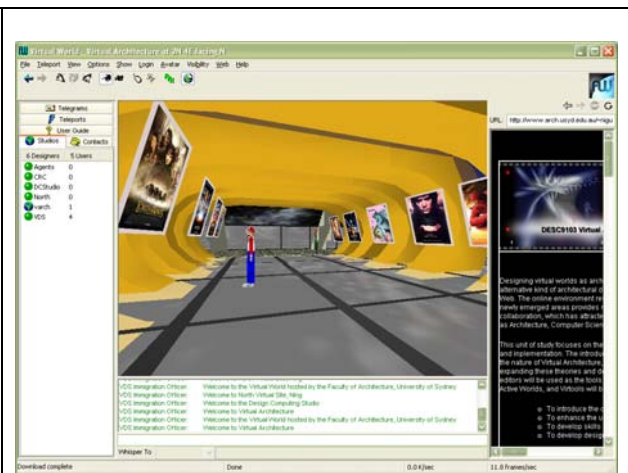


Figure 2.3. A virtual cinema in the AW University of Sydney universe, designed by the students.

⁵ <http://www.activeworlds.com>

⁶ <http://www.blaxxun.com>

⁷ <http://www.secondlife.com>

⁸ <http://www.opencroquet.org>

⁹ <http://www.virttools.com>

¹⁰ <http://www.idsoftware.com>

Blaxxun Platform 7 (BP) is developed with a strong focus on supporting virtual communities. BP provides different community design options by defining a series of sample community places comprising virtual neighborhoods, homes and other 3D venues. Occupants choose different design options to customise their own communities. Various built-in BP functions, such as member profiles, message boards, calendars, chatting, voting can be integrated to the community places to support different activities. Figure 2.4 shows the demo world of BP.



Figure 2.4. The demo world of Blaxxun Platform 7¹¹.

The sense of virtual communities is even stronger in Second Life (SL). Besides gaming, online communication and other common virtual community activities, SL also encourages trading virtual estates and properties. SL provides internal modelling tools for designing and implementing virtual worlds by manipulating geometric primitives. Behaviours of virtual world objects and avatars can be controlled using Linden Script Language (LSL). Figure 2.5 shows an entrance area in SL.



Figure 2.5. An entrance area in Second Life.

Croquet develops 3D virtual worlds, essentially for the purpose of online collaboration. It enables occupants to share not only virtual world objects but also other software applications through the virtual worlds. As indicated in Figure 2.6, Croquet focuses on its capabilities for supporting online collaboration via shared objects and tools, rather than developing 3D virtual worlds as places.



Figure 2.6. A virtual world developed using Croquet (image taken from the Croquet Project website¹²).

¹¹ <http://demo.blaxxun.com>

Virtools provides a powerful array of tools for developing 3D virtual worlds and other web-based applications, including the main component: a visual programming system which is extendable via a scripting language and SDK, and other add-on modules for implementing simple AI, databases, and multi-user functions. Figure 2.7 shows a popular multi-user internet game developed using Virtools. Compared to the other 3D virtual world design platforms, the key virtual world features such as building, avatar movement, online communication and so on that are normally provided by the platforms are not innate parts of Virtools. Virtools can realise and even extend these features, but they need to be defined and programmed separately, which can be time consuming, and technically challenging for many designers.



Figure 2.7. A multi-user internet game: Flower Power Shooter¹³ developed using Virtools.

Based on the review above, we can notice that current virtual worlds have the following characteristics in common.

- The current procedures for virtual world design and implementation are cumbersome, and rely heavily on designers' manual inputs.
- As in the physical world where different places are designed and constructed for specific purposes prior to their uses, current virtual worlds are pre-defined by designers and do not necessarily reflect changing needs arising through the use of the environments.

The GDA approach of this study is developed to address the above concerns.

2.2 STYLISTIC CHARACTERISATIONS OF VIRTUAL WORLD DESIGNS

To characterise art and design we usually refer to the concept of style (Schapiro 1953). The meaning of style varies from domain to domain. In general, styles can be understood as conventions or agreements that are used to recognise similarities or differences among design instances for design studies and design practices. A specific style is exemplified when several design instances “each create a similar impression” (Stiny and Mitchell 1978). Depending on the actual design domain, the style may be further described with a set of formal properties such as shape, colour, arrangement, texture, size and orientation (Kirsch 1998). The study of style is mainly concerned with the characterisation of these properties. In the context of architecture, the purpose of these characterisations are summarised once again by Stiny and Mitchell (1978) as “(1) it should clarify the underlying commonality of structure and appearance manifest for the building in the corpus; (2) it should supply the conventions and criteria necessary to determine whether any other building not in the original corpus is an instance of the style; and (3) it should

¹² <http://www.opencroquet.org>

¹³ <http://www.virttools.com/applications/games-fps.asp>

provide the compositional machinery needed to design new buildings that are instances of the style”.

Architectural designs have a long association with styles. The charm and complexity of architectural styles lies in the reflections of their cultural references, geographical references, historical references and references to individual artistries. Unlike architectural designs, virtual world designs have a rather shallow base to study styles. As a relatively new area, it has less-developed design theories and principles, and examples of virtual worlds are comparatively limited. The rest of the section therefore simply aims at summarising the characterisations that distinguish virtual world designs by observing some current examples of virtual worlds. We call these characterisations stylistic characterisations of virtual world designs.

2.2.1 Four Design Phases of Virtual Worlds

The view of virtual worlds as functional places that support an extended range of activities online provides a common ground for designing virtual worlds. This common ground highlights two key issues: activities and metaphor. Firstly, virtual worlds exist for certain purposes supporting various professional activities. Secondly, virtual world designs apply the metaphor of architecture. Based on this understanding, designing virtual worlds can be divided into the following four phases:

- To layout virtual places/areas in the world: each virtual place/area has a purpose that accommodates certain intended activities online.
- To configure the virtual places/areas: each virtual place/area is then configured with certain objects, which provides visual boundaries of the place/area and visual cues for supporting the intended activities.
- To specify navigation methods: navigation in virtual worlds can be facilitated to consider the use of way finding aids and hyperlinks for assisting the occupants’ movements among different virtual places/areas.
- To establish interactions: in general this is a process of ascribing behaviours to selected objects in each virtual place/area so that the occupants can interact with the virtual place/area and with each other.

Based on the results of each design phase, virtual world designs can be characterised in terms of visualisation (layout and object design), navigation and interaction. These are the three inseparable parts that provide an integral “impression” of virtual worlds.

2.2.2 Visualisation

First of all, the visualisation of virtual worlds is affected by the use of the architectural metaphor. For example, in Figure 2.8, the image on the left shows a virtual campus design that strictly applies the metaphor of a campus, one in which visitors can find familiar references to their experiences in a physical campus. The image on the right is a virtual museum design that applies a more abstract metaphor and introduces different visual elements in addition to the conventional element that can be found in a physical museum. Visitors in this virtual museum need to explore and learn about the semantics of the abstract metaphor in order to fully absorb the environments.

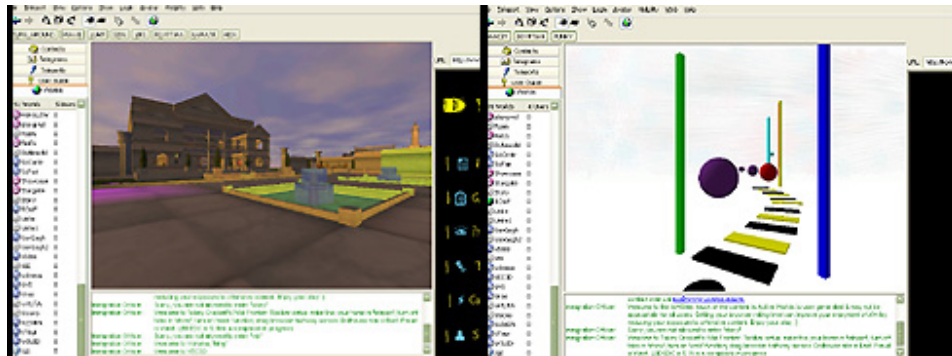


Figure 2.8. Two examples from the AW educational universe (from left to right): Wec3D virtual campus and TCWF virtual museum.

The style of the applied architectural metaphor also affects the visualisation of virtual worlds. In Figure 2.9, the image on the left is the reconstruction of a village, depicting the style of Van Gogh's paintings, whilst the image on the right shows a rather modern building.

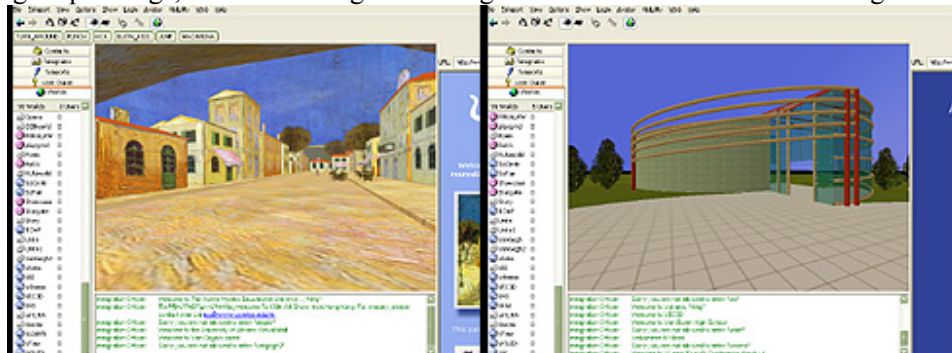


Figure 2.9. Two examples from the AW educational universe (from left to right): VanGogh world and VLearn e-learning centre.

Different uses of forms and layouts for virtual worlds can also change the visualisation. For example, in Figure 2.10 the design shown on the left uses rectangles, one of the geometric primitives, as the basic design element. In contrast, the design shown on the right uses a more organic form. In Figure 2.11, the design on the left has its layout expanded vertically, following a spiral curve, while the one on the right has the layout expanded horizontally along a floating path.

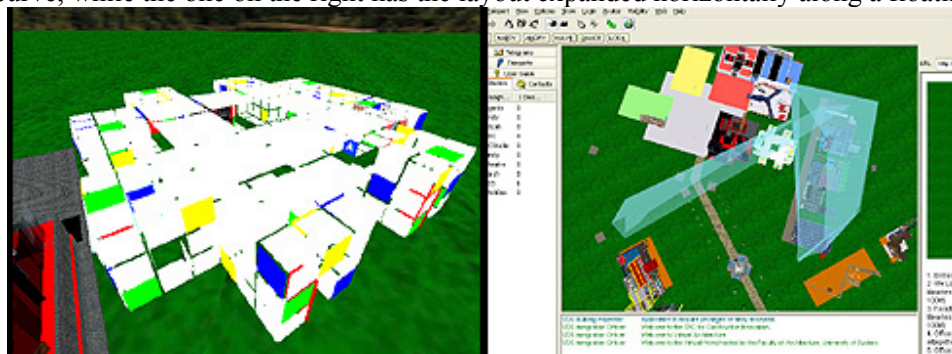


Figure 2.10. Two examples from the AW University of Sydney universe, designed by the students (form left to right): a virtual gallery and an information centre.

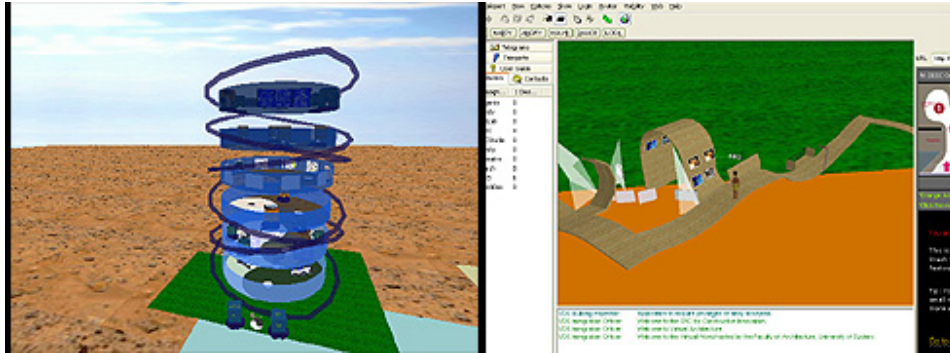


Figure 2.11. Two examples from the AW University of Sydney universe, designed by the students (from left to right): a virtual studio and a virtual gallery.

Finally, without comparing the actual contents of virtual worlds, the use of different design platforms, digital media and rendering engines can provide a different “look” to each design.

2.2.3 Navigation

Navigation in virtual worlds has been studied with direct reference to way finding aids in the physical world (Vinson 1999, Darken and Sibert 1996, 1993). There are at least two kinds of way finding aids that can be integrated into virtual worlds from the physical world:

- The use of spatial elements; for example, paths, openings, hallways, stairs, intersections, landmarks, maps, signs and so on.
- The use of social elements; for example, the assistance gained from tour guides (softbots) or other occupants.

Besides these way finding aids originating from the physical world, virtual worlds also have their unique forms of navigation where virtual places/areas are hyper-linked. Most virtual worlds allow occupants to move directly between any two locations using hyperlinks. For example, in virtual worlds implemented using AW, there are two kinds of hyperlinks for navigation purposes:

- Teleport portals: hyperlinks that take occupants from one location to another location in a virtual world, or from one virtual world to another virtual world without transitive movements.
- Warp portals: hyperlinks that take occupants from one location to another location in a virtual world with transitive movements.

The origin of hyperlinks used in virtual worlds can be traced back to navigation in hypertext systems (Dourish 1999, Ruddle et al 1997).

For example, in Figure 2.12, the design shown on the left has its areas spatially adjacent to each other. Therefore, avatars can travel from one area to another by following the relevant paths, signs and openings. The image in the middle is an interactive map for a virtual gallery. This map appears at several key locations of the gallery. Visitors can mouse-click on areas that are marked with numbers to teleport directly to the indicated locations in the virtual gallery. The image on the right captures a snapshot of a conversational softbot in Active Worlds. This softbot is able to guide the occupants by responding to their general enquires.

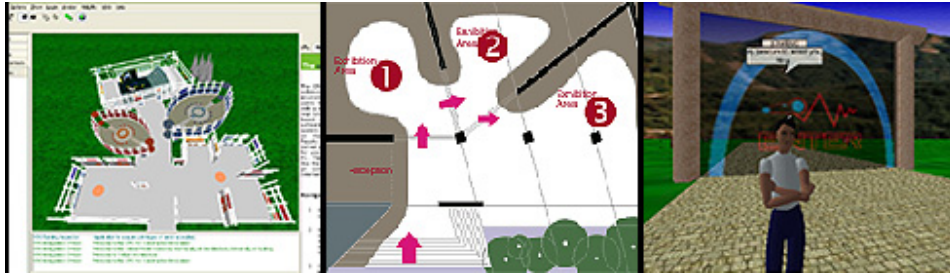


Figure 2.12. Three examples from the AW University of Sydney universe: (left) a bird view of CRC world; (middle) an interactive map used in a virtual gallery designed by the students; (right) a snapshot of a conversational softbot.

In many design platforms; for example, AW, hyper links are integrated with visual cues as part of the design. They are called portals. For example, in Figure 2.13, the image on the left shows two sets of sculptures along a path. Each of them can be mouse-clicked to teleport to a different place. In some designs, the visual cues of portals are hidden. For example, the image in the middle shows a tunnel in a virtual maze design. There are hidden objects placed in the tunnel. When an avatar bumps into a hidden object it warps the avatar until the avatar reaches the end of the tunnel. In other design platforms, hyper links may not connect to the visualisation of the design. For example, in a virtual museum implemented using Virtools, shown on the right of Figure 2.13, visitors can choose to visit the four different sections of the museum by pressing different keys on their keyboards.

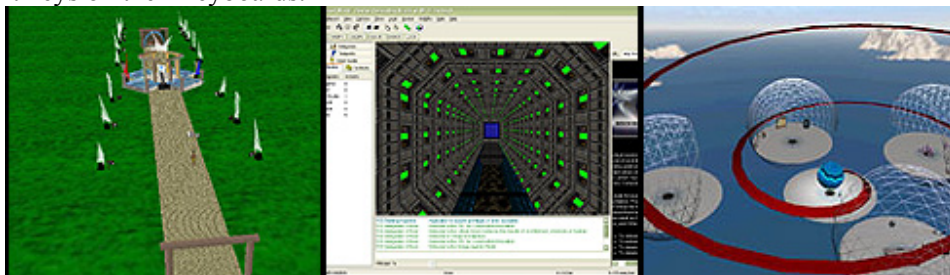


Figure 2.13. Two examples from the AW University of Sydney universe: (left) VDS world and (middle) a virtual maze both designed by the students; and (right) a virtual museum designed using Virtools.

2.2.4 Interaction

Interactions in virtual worlds are realised by triggering the behaviours of relevant objects. For example, in AW, behaviours can be triggered by “create”, “activate” and “bump”.

- “Create” automatically triggers the behaviours of the virtual world objects once the objects are loaded to the virtual worlds without further involvement by the occupants.
- “Activate” requires the objects to be mouse-clicked in order to trigger the behaviours. When an occupant intentionally performs a mouse-click action, he/she is expecting some consequences. Therefore, the occupants are given certain degrees of control over the interactions with the worlds.
- “Bump” requires that objects be collided with by the avatars of the occupants in order to trigger the behaviours. When an avatar accidentally bumps into some virtual world objects (especially the hidden objects) and triggers their behaviours, the occupant encounters the interactions unexpectedly. In this way, the designers are able to express their design intentions more assertively.

Some designers ascribe behaviours to selected virtual world objects and carefully arrange the ways to trigger them in the virtual worlds to create very interesting designs. For example, Figure 2.14 illustrates three different states of a virtual studio showing how the studio can respond differently to the existence of its occupants by having the transparency of its components being switched on and off accordingly.

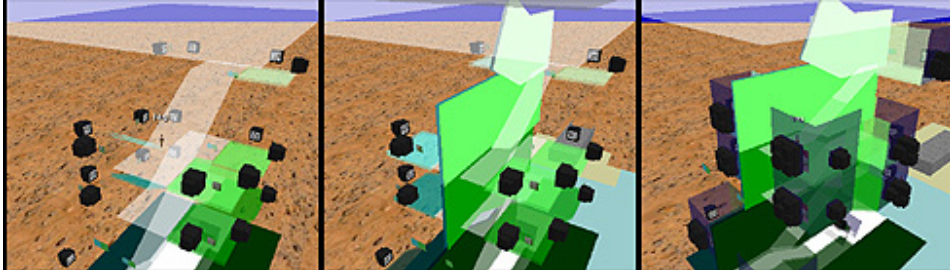


Figure 2.14. A virtual studio designed by students at the University of Sydney.

Based on the above review, we can see that virtual world designs can be characterised in terms of visualisation, navigation and interactions. Due to the use of the architectural metaphor, some of these characterisations can find similarities to styles in the physical world. However, virtual world designs also have many unique stylistic characterisations that are different from their physical counterparts, especially in terms of navigation and interaction. Virtual worlds that are designed with these stylistic characterisations in mind are more likely to achieve a sense of consistency and coherency, which more over can assist people to better orientate and navigate in the worlds.

2.3 AGENT MODELS

A GDA is a rational design agent. A brief review on agent-based computing, especially existing agent models for virtual worlds, is useful to the development of the GDA model.

2.3.1 Rational Agents

While agent-based computing started in the 1970s, recently the concept of agents has become important for internet applications, drawing on ideas from artificial intelligence and artificial life. There is no universal definition for the term agent. However, in the context of computer science, agents as intentional systems operate independently and rationally, seeking to achieve goals by interacting with their environment (Wooldridge and Jennings 1995).

An agent is always located in an environment, it receives inputs from the environment, and acts autonomously upon the environment. According to Russell and Norvig (2003), agents are distinguished from objects and other computer programs, by a constraint of rationales on the agent's beliefs, goals and actions. As shown in Figure 2.15, Russell and Norvig's reflex agent diagram (2003) illustrates the basic interaction between an agent and its environment. The agent reasons about the condition of its environment and acts based on condition-action rules. Their utility agent diagram (2003) shown in Figure 2.16, illustrates a rational agent with additional beliefs and more complex reasoning processes.

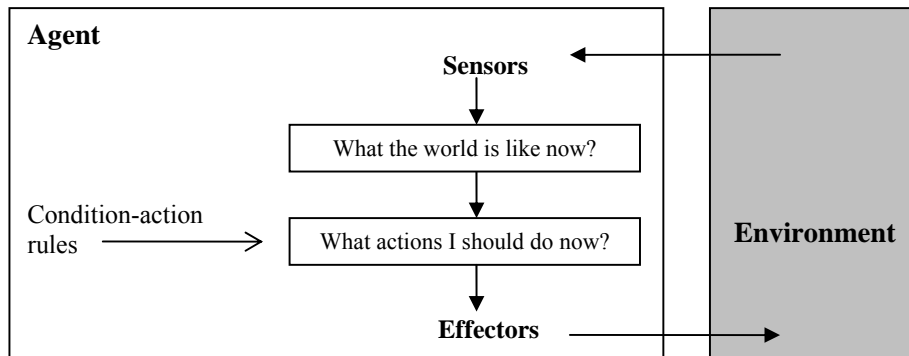


Figure 2.15. Reflex agent (after Russell and Norvig 2003)

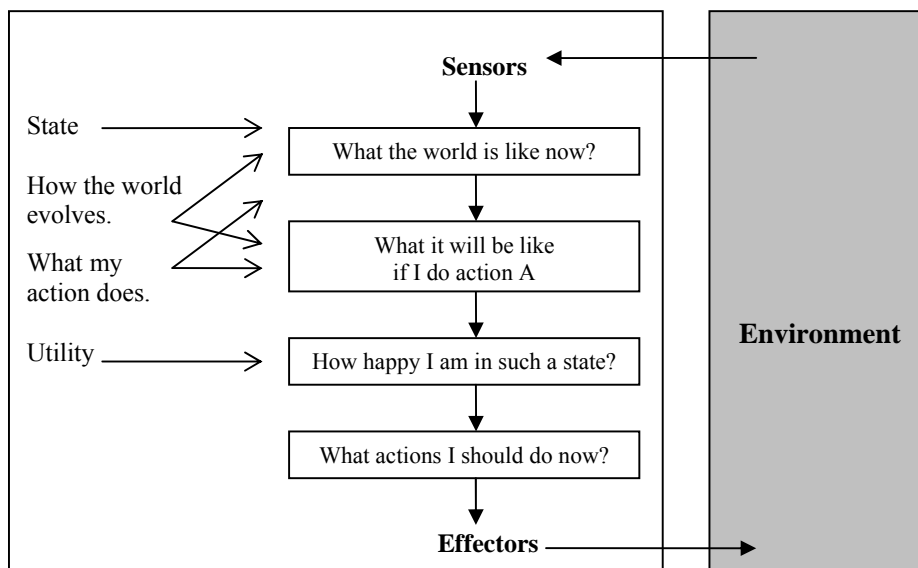


Figure 2.16. Utility agent (after Russell and Norvig 2003)

An agent has the ability to operate usefully by itself; however, the increasing interconnection and networking of computers is making this situation rare. Most problems require the agent to interact with other agents (Huhns and Stephens 1999). Hence the concept of the multi-agent system is introduced with appliance of distributed artificial intelligence. Ferber (1999) defines a multi-agent system to include the following elements:

- An assembly of agents.
- An environment where agents are located.
- A set of objects which are located in the same environment. These objects are passive, which means that they can be perceived, created and manipulated by the agents.
- An assembly of relationships.
- An assembly of operations for agents to perceive, create and manipulate.
- Operators for pursuing the operations.

2.3.2 An Agent Model for 3D Virtual Worlds

Maher and Gero (2003, 2002) develop a common agent model for 3D virtual worlds aiming at increasing the level of interactivity for virtual worlds. The agent model is applied so that virtual

world objects can respond more generally to their uses. Such responses can result in a dynamic world that configures and reconfigures itself as needed.

As shown in Figure 2.17, using this model each virtual world component can be represented as an agent element, and a virtual world can be represented by a society of agents; for example, wall agents, door agents, room agents or building agents. Each agent is able to sense and respond to its use in the virtual world by reasoning about the current state of the virtual world. The agent model provides a common vocabulary for describing, representing, and implementing agent knowledge and communication. In this common agent model, key agent components and computational processes are outlined for supporting interactions between the agents and the virtual world, and interactions among different agents in the virtual world. An agent developed using this common model interacts with the virtual world via sensors and effectors, and has five kinds of reasoning: sensation, perception, conception, hypothesizer and action.

- Sensation transforms raw inputs from the sensors into data that are more appropriate for agent reasoning and learning.
- Perception is a process that finds grounded patterns of invariance in the agent's representation of the sense data for constructing concepts.
- Conception learns and uses concepts to reinforce or modify the agent's beliefs and goals.
- Hypothesizer identifies mismatches between the current and desired state of the virtual world and hypothesises goals in order to reduce or eliminate mismatches.
- Action reasons about the sequence of operations on the virtual world, when executed, can achieve the agent's goals.

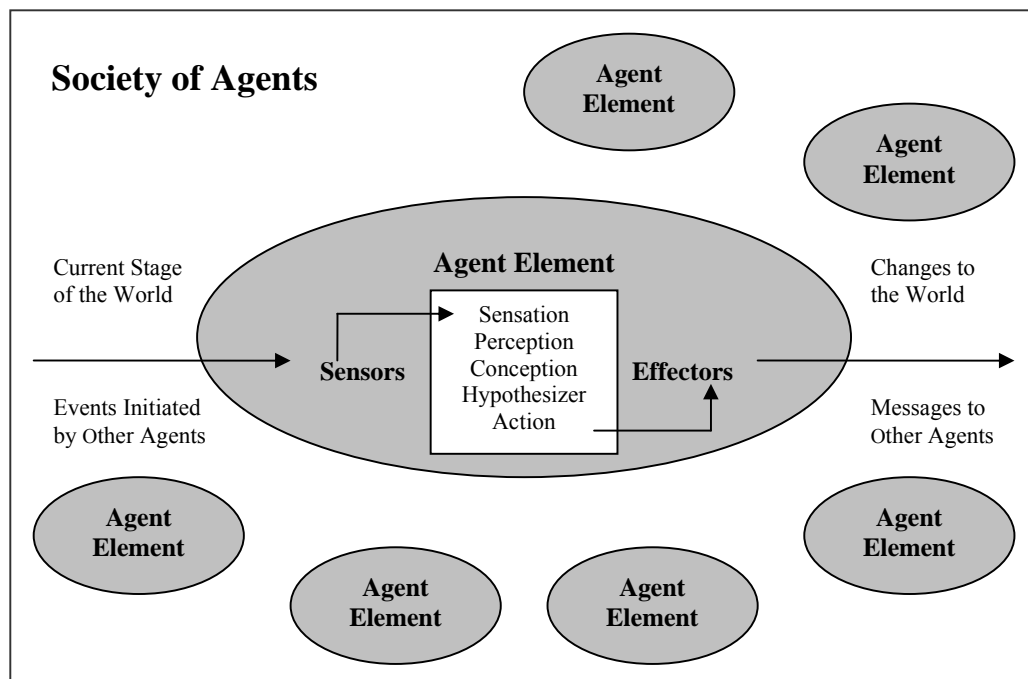


Figure 2.17. A virtual world as a society of agents (after Maher and Gero 2003, 2002).

This agent approach to virtual worlds provides new kinds of interactions not only among the virtual world elements, but between these elements and the virtual world occupants. Using such a reasoning mechanism, agents can function in three different modes: reflexive, reactive, and reflective. Each mode requires a more sophisticated reasoning mechanism.

- Reflexive mode: the agent responds to sense data from the environment with pre-programmed responses. This mode is equivalent to the kinds of behaviors that are available in most virtual worlds. Reflexive mode is the simplest among the three.
- Reactive mode: the agent's reasoning involves both the sense data, the perception processes that manipulate and operate on these data, and knowledge about the processes.
- Reflective mode: the agent filters its sense data depending on its current goals and beliefs. The agent also adjusts its perception processes depending on its current goals and beliefs, which may lead to changes in its concepts. The reflective mode includes all these dynamics to allow the agent to adjust its interests accordingly.

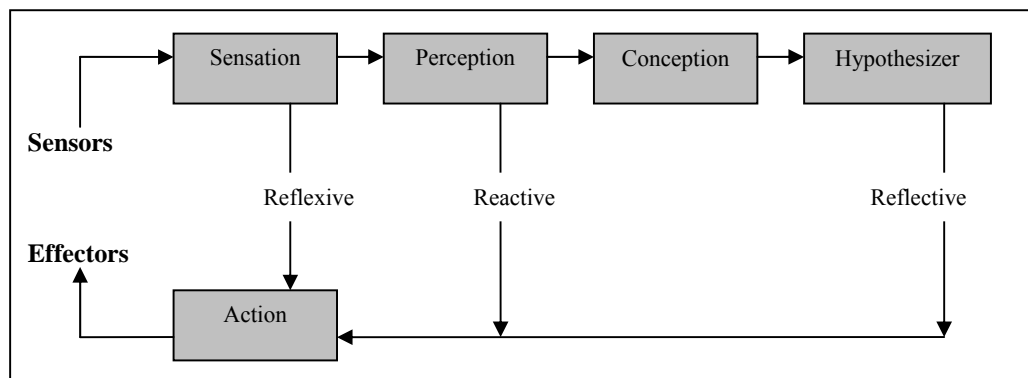


Figure 2.18. A common agent model for 3D virtual worlds (after Maher and Gero 2003, 2002).

Taking together the advantages of rational agents being capable of operating independently and rationally, and who seek to achieve goals by interacting with their environment, this study proposes that rational design agents serve as personal assistants for virtual world occupants in order to dynamically design, implement and manipulate virtual worlds as needed through real-time interactions. The GDA model developed for this study is illustrated in Chapter 3 with progressive diagrams that show the development of the model and its relation to other agent models introduced above.

2.4 SHAPE GRAMMARS

Shape grammars (Stiny and Gips 1972) as a design formalism and their applications have been developed over the past three decades. A GDA's design component is supported by the application of a generative design grammar. The concepts and development of generative design grammars are inspired by the shape grammar formalism. Section 2.4 briefly reviews shape grammars and their applications. The comparison between shape grammars and generative design grammars are discussed in Chapter 4.

2.4.1 Notions of Shape Grammars

According to Knight (2000), a shape grammar is a set of shape rules that can be applied in a step-by-step manner to generate a set or language of designs. A shape grammar is both descriptive and generative. The application of the shape rules generates designs, and the rules themselves are the descriptions of the forms of the generated designs. In general, applications of shape grammars have two main purposes. On one hand, shape grammars can be used as design tools to generate vast varieties of design languages. On the other hand, shape grammars as design analysis tools

can be used both to analyse existing designs in order to better understand these designs, and to generate shape rules that produce the designs and other similar designs.

Stiny (1980) defines four basic components of a shape grammar:

S: a finite set of shapes.

L: a finite set of symbols.

R: a finite set of shape rules.

I: initial shape.

Each shape rule follows the form of $S_a \rightarrow S_b$. S_a and S_b are two different labelled shapes.

Shape grammar theories have developed over the years to include many extensions, such as parametric grammars, color grammars, description grammars, structure grammars, parallel grammars, and so on, to address different aspects of designs.

2.4.2 Shape Grammars and Design Styles

Shape grammars are advanced in a number of ways. Shape grammars are able to apply simple shape rules to produce designs with rich descriptions. Shape grammars enable different designs that share a similar style to emerge by alternating the sequence of shape rule application. By analysing existing designs of a known style, shape grammars can formally describe this known style and generate other designs that also share the style. Further, by incorporating additional devices, shape grammars are able to describe and generate new design languages in an extension to the original languages.

According to Knight (1994), to develop a shape grammar to describe and generate a known style involves the following steps:

- To define a vocabulary of shapes and a set of spatial relations that are common to the design instances of the style.
- To define shape rules that fix the occurrences of the spatial relations.
- To provide an initial shape to start the application.

Following the above steps, a shape grammar can be developed to produce a specific design language. Further, through transformations using rule addition, rule deletion or rule change, this shape grammar can be transformed into a new shape grammar. In this way a new design language emerges.

2.4.3 Design Constraints and Shape Grammar Application

One critical issue in the application of shape grammars for design is how to develop a grammar that produces designs which meet the design goals or constraints that are set for the design brief. According to Knight (1999), there are two different approaches that address this issue. The first approach is to incorporate foreknowledge into shape rules so that the generated designs could meet the given goals. To a certain extent, this approach is about constraining the grammars in order to control the shape rule application and increase the predictability of the outcomes. Knight (1998a) has analysed a list of six different types of shape grammars ranging from unrestricted, standard shape grammars with the least predictable outcomes, to simple, restricted ones with the most predictable outcomes. The first approach requires adequate design knowledge while developing the shape grammar. The other approach assumes inadequate design knowledge while developing the shape grammar. In the second approach, the shape grammar is allowed to generate designs without being constrained. After the designs are generated, an automated search and test device is then applied to search through the design space, test the designs and then select the ones that meet the given goals or satisfy the given constraints.

2.5 SUMMARY

The background chapter provides three important insights that have shaped the work presented in the remainder of the thesis.

- Current virtual worlds are pre-defined by designers and do not necessarily reflect the changing needs that arise during the use of the environment. The current procedures for virtual world design and implementation are cumbersome, and rely heavily on manual inputs.
- The current state of virtual worlds can be improved. By applying the rational design agents the GDAs, this study aims to develop a different kind of virtual world that is dynamically designed and implemented as needed, and without being pre-defined prior to its use.
- To support the design components of the GDAs, this study presents a generative design grammar framework that provides guidelines and strategies for developing generative design grammars. Drawing inspiration from shape grammars, generative design grammars as a design formalism are applied by the GDAs to generate virtual world designs with certain stylistic characterisations in mind.