A GRAMMAR FOR THE DYNAMIC DESIGN OF VIRTUAL ARCHITECTURE USING RATIONAL AGENTS

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Abstract. Virtual Architecture is a virtual place that uses the metaphor of architecture and provides an online environment for various human activities. While Virtual Architecture inherits many of the characteristics of physical architecture, it is possible to reconsider the virtual in terms of flexibility and autonomy. This paper presents a User-centred Virtual Architecture (UcVA) Agent, a kind of rational agent capable of representing a person in virtual worlds and designing virtual worlds based on current needs. The UcVA agent model has a design component that uses the shape grammar formalism. This model and a sample grammar are demonstrated for a meeting room scenario.

1. Introduction: An Agent Approach to User-centred Virtual Architecture

The design and development of virtual worlds has focused on the implementation and rendering of the 3D models that provide the place infrastructure. While Virtual Architecture can be understood as having its roots in physical architecture by providing 3D infrastructure, the software available to build virtual worlds makes it possible for these worlds to be highly interactive and dynamic. From this perspective, designing Virtual Architecture can go beyond the conventional 3D modelling and construction processes of traditional Architecture to apply agent models (Maher and Gero, 2002; Maher and Gu, 2002) as the basis for its representation and implementation. This research involves the development of user-centred agent models for Virtual Architecture that builds on implementations of virtual worlds, but also includes design agents (Maher and Gu, 2002). This leads to the development of virtual architecture that is dynamically designed and implemented as needed, without the legacy of the persistent infrastructure of physical architecture.

In a "user-centred" approach to Virtual Architecture, the central component is a Rational Agent (Wooldridge, 2000). A rational agent is a system that operates independently and rationally, seeking to achieve its goals by interacting with its environment. It has goals and beliefs and executes actions based on those goals and beliefs. This distinguishes a rational agent from the computational agents that perform actions based on predefined events, such as search agents on the web. A User-centred Virtual Architecture (UcVA) Agent is proposed as a rational agent for dynamically designing and implementing virtual architecture. This agent, on one hand represents a person from the real world as an Communication Agent in the virtual world capable of providing a kind of agency for collaborating with other agents and interacting with the virtual world, and on the other hand acts as a Design Agent capable of designing and constructing dynamic virtual places for the UcVA Agent as needed. Hence virtual architecture becomes user-centred which means the virtual places will be created dynamically based on the current needs.

2. User-centred Virtual Architecture Agent Model

Researchers have been studying rational agents with various foci. The Reflex Agent and Utility Agent (Russell and Norvig, 1995) examine the representation models of a single agent and the reasoning processes involved. Maher and Gero (2002) study a society of agents, in which a single agent is represented as a component of a virtual world with an existing infrastructure. Our study looks at the UcVA agent with the focus centred around design activities. A UcVA Agent has two major structural components: the Communication Agent part and the Design Agent part. The Communication Agent part represents a person in the virtual world. It provides a kind of agency in the virtual world for communicating and collaborating with other agents and interacting with the environment. The Design Agent part develops virtual architecture as needed for UcVA Agents by applying design rules. Hence a community in the virtual world could be represented by a society of UcVA Agents, which are able to interact with each other and construct virtual architecture dynamically. Figure 1 is a UML diagram showing the two major components of a UcVA Agent.

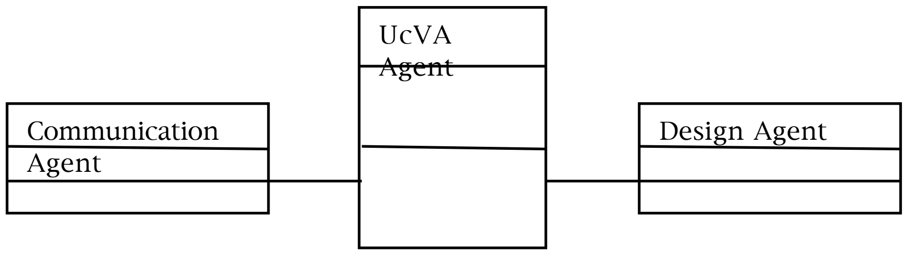

Figure 1. A UML diagram of a UcVA Agent without specifying attributes and operations.

The computational processes consider the reasoning procedures within an agent, which identify how it reasons about other agents and the virtual world. Based on the five main computational processes in an agent model for 3D virtual worlds outlined by Maher and Gero (2002): Sensation, Perception, Conception, Hypothesizer and Action Activation, the following computational processes have been adapted for the development of the UcVA Agent:

1. Sensation: transforms raw inputs from the virtual world into something more appropriate for reasoning and learning.
2. Perception: finds patterns in the sense data that are used in developing the agent's concepts of the virtual world.
3. Conception: assigns meaning to the patterns that situates these patterns in the context of virtual world.
4. Hypothesising: identifies the design goals for the agent based on comparing its expectations with the current state of the virtual world.
5. Design: reasons about how to achieve the design goals by selecting, combining, and locating elements that comprise the design.
6. Action Activation: identifies the actions needed to build the design given a design description.

3. Implementation of the UcVA Agent with A Design Scenario

The UcVA Agent in this paper is implemented and demonstrated for a meeting room scenario in a virtual world powered by Active Worlds[1] (AW), a multi-user three-dimensional virtual environment. Each person in the virtual world is represented by a UcVA Agent, that is an avatar (three dimensional animated character) for visualisation and navigation purposes, plus an agent model for reasoning purposes. When two persons greet with each other in the virtual world, the UcVA agent for each person reasons about the dialogues. When they decide to have an online meeting, the agents design and construct a meeting room in the virtual world.

With the scenario provided, we now further look at the implementation of the UcVA Agent model. The six computational processes as the knowledge core of the UcVA Agent will be implemented with Jess, a rule-based production system scripting language. However, the focus of this paper is on the development of a grammar for the Design process based on an existing virtual world design.

3.1. SENSATION

In Sensation, the raw data sensed from the virtual world environment are asserted as facts to the working memory of the agent. Upon the point when avatar “Mary” and avatar “Ning” enter, the relevant data sensed from the virtual world are:

1. The virtual world.
2. Objects in the world and their locations.
3. Avatar Mary and avatar Ning and their locations.
4. Chat text by the above two avatars.

3.2. PERCEPTION

The two avatars start moving around and chatting with each other. The agent receives new locations of the avatars and their online conversation dialogues. The agent is able to recognise the keyword “meeting”, which indicates that the avatars might want to have a meeting session. In addition, the agent also performs a count on the number of the avatar(s), in order to prepare for the further reasoning in the Conception process.

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[1] http://www.activeworlds.com/

3.3. CONCEPTION

From the Perception process, the agent is able to perceive the keyword “meeting’ from the avatars’ dialogues. In the Conception process, the agent will further look at this keyword and its relationships with other percepts, such as the number of the avatars in the virtual world, and other relevant information received from the Sensation process.

3.4. HYPOTHESISING

Once the need of having a meeting for two avatars is known, the agent reasons about possible solutions for satisfying this need. One solution is to set a goal to design a place for the meeting.

3.5. DESIGN

The Design process is a reasoning process for generating design solutions in order to satisfy the goal(s) established in the Hypothesising process. The current implementation of the design agent uses the shape grammar formalism (Stiny and Gips 1972, Knight 2000).

3.5.1.Shape Grammars

Shape grammars as a design formalism and their applications have been developed for over three decades. Knight (2000) summarises the definition and the components of a shape grammar: a shape grammar is a set of shape rules that apply in step-by-step way to generate a set, or language of designs. A shape grammar is both descriptive and generative. The shape rules are the description of the spatial forms of the designs. They can also relate to the goals of a project that may describe anything from functions to meanings to aesthetics and so on. The basic components of the shape rules are shapes. Shapes can be understood as points, lines, planes or volumes. The designs are generated using shape operations. They are addition, subtraction and spatial transformation such as rotating, shifting and mirroring.

3.5.2. Shape Grammars and Designing Virtual Architecture

Virtual Architecture could be represented in terms of a Conceptual Basis, a Semantic Frame and a Visual Shell (Maher, Gu and Li, 2001). The first two elements construct the functional aspect Virtual Architecture, with which the supports for various kinds of online activities become possible. The last element could be seen as the visualisation of the first two elements. Hence the representation of Virtual Architecture could be also perceived as a functional core and a visual shell. Shape rules are capable of describing these two aspects. In the case of designing virtual worlds, the shape rules have the following two layers of meanings:

1. They are the descriptions of spatial forms of the architectural design in the virtual domain with an analogy to the physical world.
2. They are the descriptions of functions that support certain kinds of online activities.

The first layer relates to the generation of forms, the second layer requires the attachment of certain functional aspects to the forms generated in the first layer.

Designing Virtual Architecture as a newly emerged filed has not yet been well developed. The design principles for Virtual Architecture are not sufficient in terms of both quantity and quality. Shape grammars as design analysis tools, could be used to analyse the existing designs in order to better understand the designs, and evolve design rules from those existing designs. Shape grammars then could be used as design tools to generate designs based on design rules evolved from the analysis stage.

Virtual Architecture could be highly dynamic compared to Physical Architecture. Virtual Architecture should be designed and evolved based on the current design situation. Including a design component as a part of the user's agent in a virtual world has the potential to realise this characteristic. Shape Grammars provide a powerful mechanism, which is able to apply basic components (initial shape, shape rules and operations) in fairly simple forms, for generating design solutions to solve rather complicated design problems. This mechanism could be applied to designing Virtual Architecture, where the various factors of the current design situation could be represented as basic components of the shape rules. The changes of these basic components would alter the result of the generated design solutions to suit the current needs.

3.5.3. Generating Shapes Rules: CRC World Analysis

Shape grammars have been applied to both generating new designs and analysing existing designs. Each grammar captures a specific design style. Therefore, each UcVA Agent could have its own grammar and its own style. We illustrate the generation of the shape rules for the Design process of a UcVA Agent with an analysis of an existing virtual world design, the CRC World. The CRC world is a virtual environment for collaborative research. It provides networked places supporting meetings/seminars for smaller groups, conferences for larger groups and exhibition/storage for collaborative projects. The design of the CRC world was not generated with Shape Grammars. However, a set of shape rules could be generated to reproduce the exact design and other designs that share a similar style with the CRC world. The style here simply means the common characteristics of using forms and representing functions, shard by a number of virtual world designs. The analysis of the CRC World aims at:

1. Identify the shape rules and their components that could generate the forms of the CRC World, to be adapted to the design of our shape grammars for generating forms in the agent/meeting scenario.
2. Analyse the functional aspects of the meeting/seminar rooms in the CRC World in order to prepare for representing the functional aspect of a meeting room in the scenario.

Firstly, the analysis is pursued in terms of the generation of forms. Architectural spaces are generated in three dimensions. The basic components of the shape rule for this purpose are usually perceived as volumes. However, the CRC world is a single-storey building block. There is also no complicated spatial intersection in the design. Hence the design of the CRC world can start from the generation of a two-dimensional plan. The two-dimensional modules will be replaced with three-dimensional units in the end. In the floor plan, the basic construction modules are square, the variation of square, rectangle, circle and the variation of circle, ellipse. The floor plan can be analysed as explicit shapes of the above modules. Figure 2 illustrates this transition. One possible way to reproduce this plan is to apply the shape rules illustrated with Figure 3, 4, 5, 6 and 7.

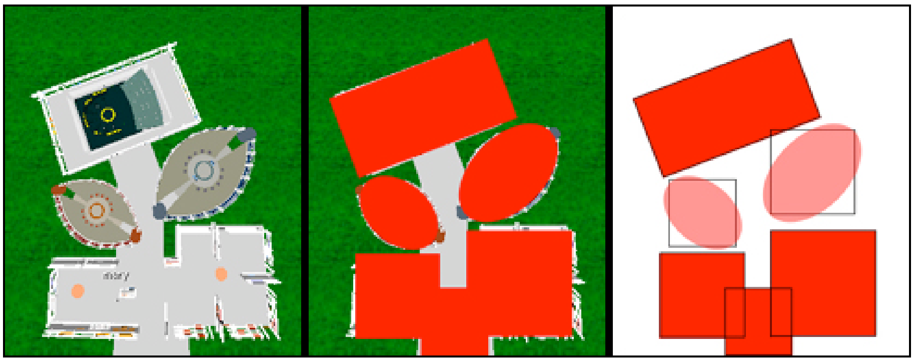

Figure 2. The floor plan (left) is analysed as explicit two dimensional shapes (right).

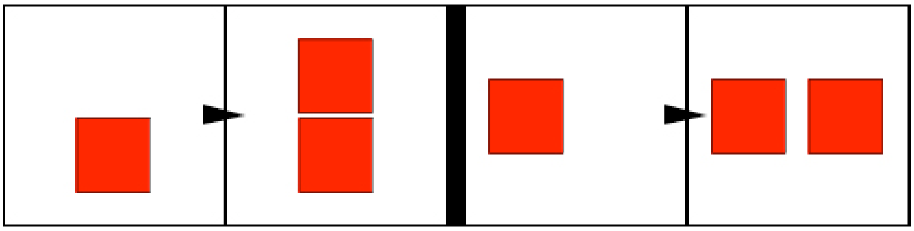

Figure 3 (from left to right). Rule 1: vertical addition; rule 2: horizontal addition.

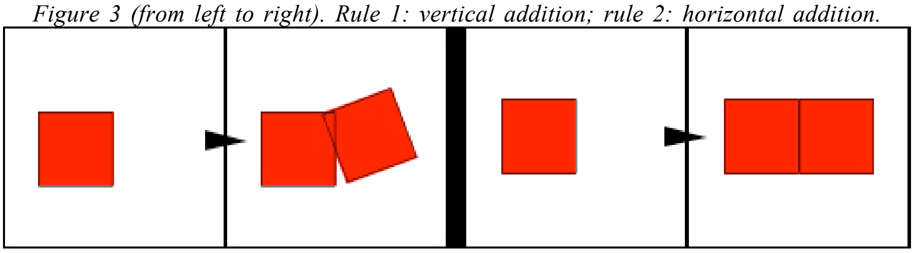

Figure 4 (from left to right). Rule 3: rotation; rule 4: horizonta addition.

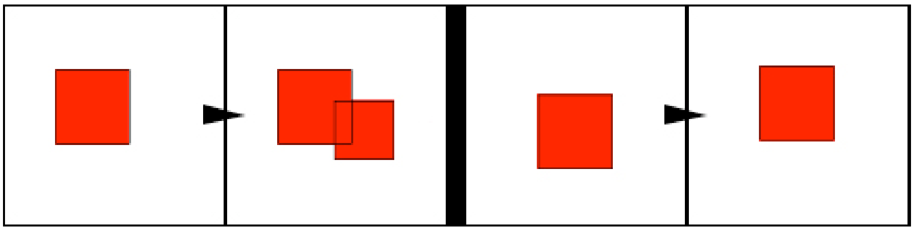

Figure 5 (from left to right). Rule 5: diagonal addition; rule 6: vertical transformation.

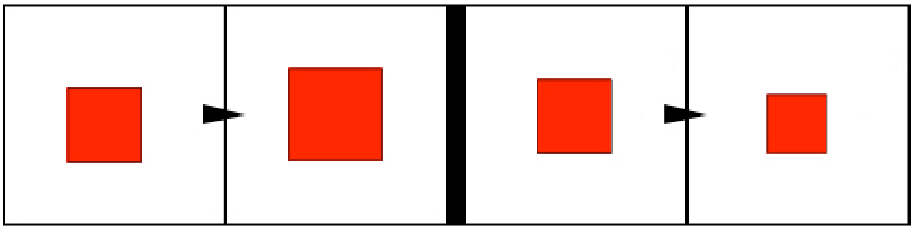

Figure 6 (from left to right). Rule 7: scaling-up; rule 8: scaling-down.

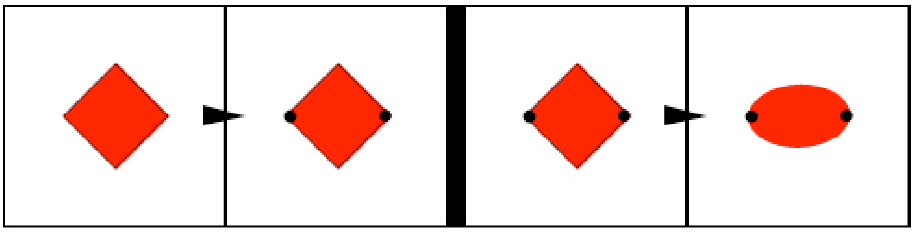

Figure 7(from left to right). Rule 9: addition of circles; rule 4: replacement of curves.

The above rules can be applied step by step by step to generate the floor plan of the CRC World. Figure 8, 9 and 10 illustrate this process, from a chosen initial shape to the final generated floor plan.

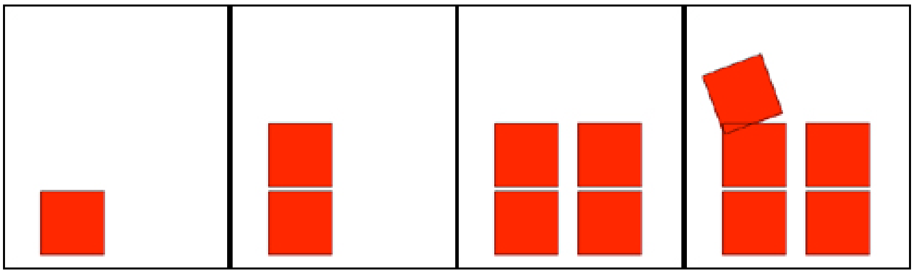

Figure 8 (from left to right).Iinitial shape: a square; step 1: to apply rule 1 once; step 2: to apply rule 2 twice; step 3: to apply rule 3 once.

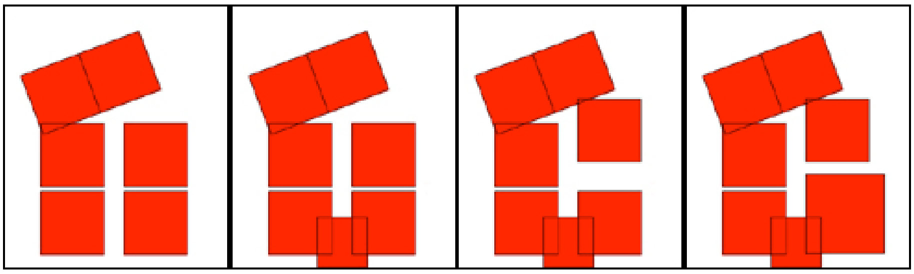

Figure 9 (from left to right). Step 4: to apply rule 4 once; step 5: to apply rule 5 once; step 6: to apply rule 6 once; step 7: to apply rule 7 once.

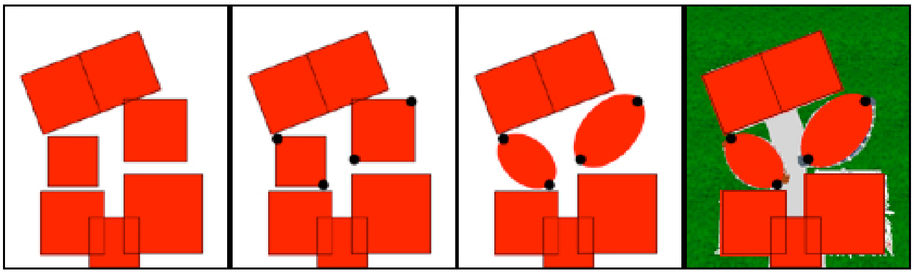

Figure 10 (from left to right). Step 8: to apply rule 8 once; step 9: to apply rule 9 twice;
step 10: to apply rule 10 twice; the comparison between the final shape and the actual plan.

The next stage is to replace the two-dimensional shapes from the above floor plan with three-dimensional units (Figure 11). Each unit corresponds to one specific kind of two-dimensional shape, which reflects on the usage of a floor with the same two-dimensional shape. The similar style of the frame-like walls used in the CRC World will then be applied to the edges of the floor to shape the vertical volumes.

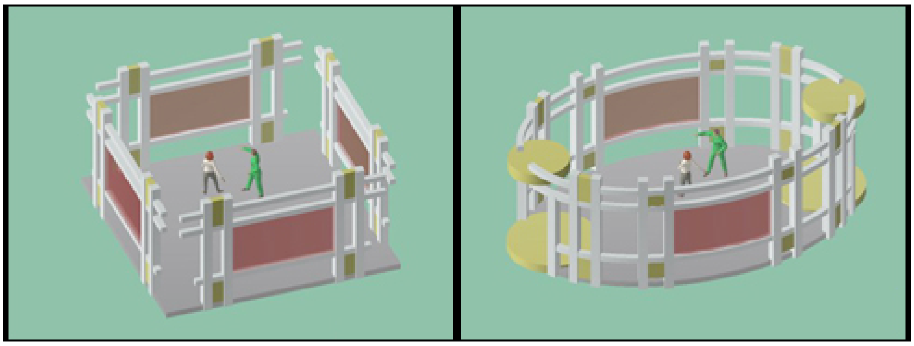

Figure 11 (from left to right). Cubical unit with four side walls and openings: to replace two dimensional square shape; oval unit with two entrances and two curve walls: to replace the two dimensional ellipse shape.

The final stage is to refine the design details, mostly to delete the repeated walls or parts of the walls in the overlapped units. This process is completed with the replacement rules (Figure 12):

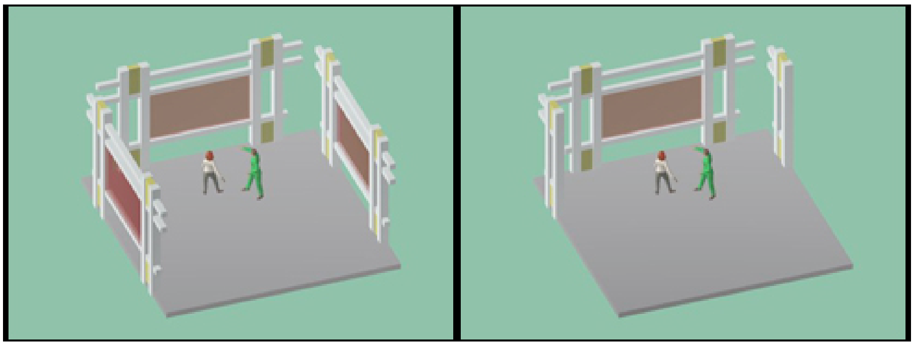

Figure 12 (from left to right). A standard cubical unit is replaced with a square unit without one side wall; a standard cubical unit is replaced with one side wall and two partitions.

The generation of the forms for the CRC World using a Shape Grammar has been completed (Figure 13). The analysis of the representation of its functional aspects is more difficult and indirect than the analysis of the generation of its forms. We choose a meeting/seminar room as the study case because the design theme of the scenario is a meeting room. The capability of a networked place for supporting certain types of online activities is related to the virtual place as a whole, rather than associated with any single part of the place. Determining the quality of the online meeting place is hard to perceive and judge, or even to describe. This quality is more related to how well the facilities or the whole place serve the purpose of supporting the target activities. It could be an individualised and subjective feeling of the user in the environment.

The approach we take for the analysis is from the first, the physical aspect. The reason is that designing in virtual worlds is currently lacking common understandings of design principles and evaluation criteria. There is not enough knowledge for mastering the second, the abstract aspect. The CRC World is implemented in AW. The structure of the worlds in AW is object-oriented. Each architectural element is not only a model for visualisation, but also a media for supporting online actions. These actions provide interactivities for supporting various kinds of online activities. It is a starting point for firstly designing a networked place that is able to support the target activities using a shape grammar. Designers then could add constraints in rules to further study how well the environment supports the activities.

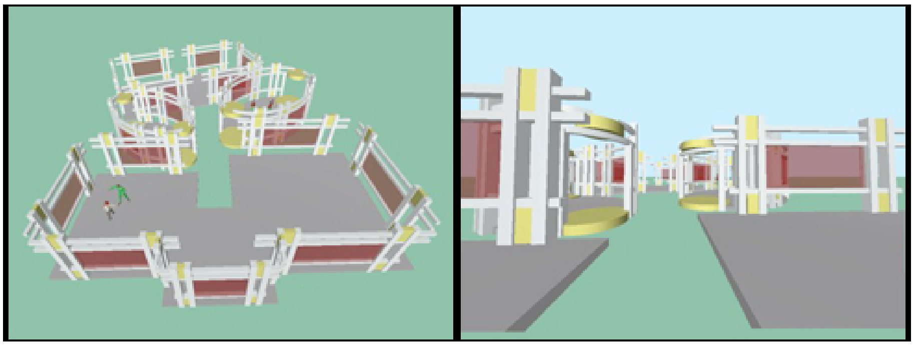

Figure 13. Two views of the re-designed CRC World using a shape grammar.

The key function of the meeting/seminar room of the CRC World is to host small meetings and seminars. In order to support these two activities, the meeting/seminar room is featured with two "screen" objects for posting slides during a presentation, each of which is placed on one side of the room, and various "sign" objects on the frame-like walls for attaching web contents related to the meeting/seminar. There is also a floating ring placed in the middle of the room to focus the avatars' attention. During the meeting/seminar session, avatars would gather around the ring. The above three objects could be perceived as the functional aspects that support the needs of having an online meeting/seminar in the CRC World. Hence we conclude the following three rules as the descriptions of functions that support online meetings/seminars.

1. If a three-dimensional unit is a meeting area, there will be a floating ring at the center of the room for gathering purposes, to focus people's attention.

2. If a three-dimensional unit is a meeting area, there will be two screens in the room for online presentation. Each of them will be placed on a side wall, opposite each other.
3. If a three-dimensional unit is a meeting area, there will be signs placed around the presentation screen for posting online documents.

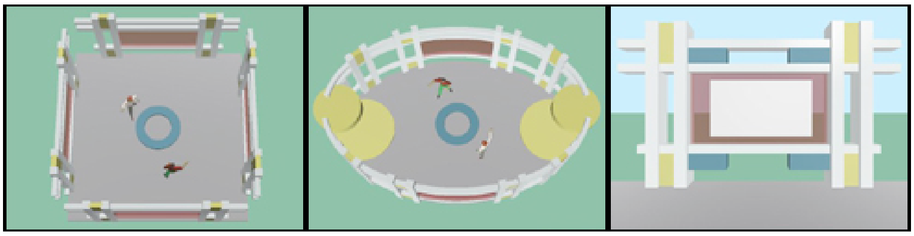

Figure 14 (from left to right). A standard cubical unit with a ring placed at the center to indicate that it is a meeting area; a standard oval unit with a ring placed at the center to indicate that it is a meeting area; a view of a side wall showing a presentation screen attached at the middle with two signs placed both above and below.

From the analysis of the CRC World design using a shape grammar, we have concluded a set of shape rules for generating CRC World-like forms and a set of rules for providing functional components for supporting online meetings. For the scenario, one more set of constraints is still needed to reflect the number of the avatars, who would be using the meeting room. This constraint could be implemented in two ways. The first one is to filter the generated designs with a certain range of areas depending on the number of avatars. The second one is to carefully specify the area of the initial shape as the module for one single avatar and then limit the times of firing addition rules according to the number of avatars. Other shape operations stay unchanged. The second approach is more desirable because it does not require the implementation of filtering devices. Hence the following constraints are specified for the grammar:

1. The initial shape is chosen to be a 8m X 8m square.
2. For less than 10 people. the addition rules are applied twice.
3. For less than 15 people, the addition rules are applied three times.
4. For less than 20 people, the addition rules are applied four times.
5. Other shape operations are not affected by the above constraint.

The above rules for generating forms, representing functional aspects of meetings and reflecting the numbers of the avatars are the major structure of the Design process for the UcVA Agent. They are the generic descriptions in the UcVA Agent's Design process. Each agent could have its own rules for designing different types of virtual architecture in various styles. In the scenario, both agents have design rules. The persons would need to choose one of the agents to perform the design tasks. The selected agent activates its design rules, generates and presents a collection of design solutions.

3.6. ACTION ACTIVATION

With one of the meeting room designs chosen by the persons in the virtual world, the Action Activation process would realise the designed meeting room in the virtual world. The selected design for the scenario is shown in Figure 15. The rectangular-shape room is the reception area and the oval-shape room is the meeting area, which is indicated by the blue ring for gathering purposes. If the persons have specified a location for building the meeting room, the agent would building the meeting room at this location and teleport all avatars there. Otherwise, the agent will build the meeting room using the current location of its own avatar, and teleport other avatars to this location.

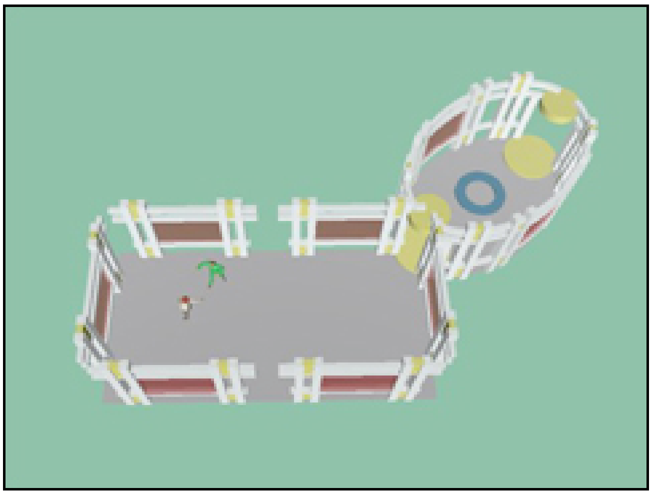

Figure 15. A bird's view of the selected meeting room design for the scenario.

The avatars would be given the option to keep the meeting room for future use. Otherwise, the meeting room will be removed from the virtual world as the session finishes. In any case the design experiences for this scenario will be saved as part of the agent's memory for future references.

4. Conclusion and Future Research

The UcVA Agent model has been proposed and implemented using a meeting room scenario. Combining the design knowledge of a shape grammar and the reasoning algorithm of the Jess production system language, the UcVA agent model provides a dynamic approach for designing and implementing Virtual Architecture. The focus of this paper was on the development of a grammar, based on the CRC World design, for the Design process as the generative part of the rational agent. The first stage of our future research will apply a more complete scenario to further study the whole reasoning process of the agent. The second stage will extend and enrich the six computational processes beyond the limit of the meeting room scenario, to support the design and implementation of Virtual Architecture in general.

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