Appendix F CVE Design Method and Guidelines

F.1 The Virtual Reality Experience

The CVE usability design method presented here makes use of the standard requirements engineering step-wise approach. The method and guidelines consist of a collection of techniques which support a design team in discussing, clarifying and documenting the design choices. Furthermore, the systematic use of this method will base the trade-off decision making process that accompanies the design task, in the larger domain of HCI, scientific discovery, and the social sciences in general. There are other documents available which cover guidelines for VE design and the development process (Carr and England, 1995; Zachmann, 1996; D’Cruz et al., 1996; Helander, 1997; Gabbard, 1997; Roberts, 1998; Weishar, 1998; Parent, 1998; Guye-Vielleme et al., 1998; Poupyrev and Kruijff, 2000, Rouse III, 2001).

The method presented here enables all members of the design team to make an assessment of the minimum usability requirements necessary to create a cognitively immersive CVE experience; allowing the CVE developers to make informed decisions on how to build usable CVEs. Decisions on the simplification of functionality and graphical representations demanded by a particular system’s performance constraints can be guided by this method.

This method uses standard usability engineering techniques, but also cognitive psychology and 3D design knowledge. First, the user context is analysed, and next the basic route for every CVE task is specified, until a detailed description of the implementation for that task has been reached. Each functional layer of the CVE is treated separately, and, each layer is presented with the appropriate techniques to gather design ideas, to support the design decision-making process. Task flow is achieved by applying generic task cycles, which help to specify the design features needed to ensure ease of use and feedback for each step of the user's task.

Before getting started with the design process - the actual task of building the CVE - one has to make sure that all elements of the design infrastructure are in place. There are two levels:

- Meta-task of building CVEs: the design infrastructure.
- Actual Task of building CVEs: the design process.

The meta-task involves creating a team, creating a role division, developing a shared vision of the future product, and clarifying any impacts of performance constraints on the design. The actual task of building the CVE involves creating a requirements analysis, creating the 3D structures, and applying narrative affordances.

Design Infrastructure

Building a design infrastructure involves creating a CVE design team comprised of members sufficient to defend all design angles involved in the process of building CVEs, such as interaction, aesthetics, computational power, project-duration, user needs, etc. Each design angle is linked to a certain set of requirements. Because design choices made to fulfil requirements in one area possibly degrade performance in one or more of the others, designing the CVE as a multi-disciplinary team is the surest way of building effectively. The following activities are part of building the design infrastructure:

- Build a team comprised of members sufficient to defend all design angles;
- Develop and maintain a shared vision of future product by holding frequent team meetings;
- Divide roles for each part of the design process amongst the team members;
- Create work-plan for team-members working in sub-groups where necessary;
- Explicitly formulate areas where trade-off decision making has impact on usability and run-time performance throughout the design process.

Each team member has a role to play and a task to fulfil, as advocated in standard engineering and user-centred design manuals. The roles that we distinguish are listed in the table F.1, together with the respective responsibilities and questions to which each member of the team should be able to guarantee an answer.

Design Role	**Responsibilities**	**Questions to be Answered**
Decision Maker Manager	Control the complete process of building a successful CVE. Guard cost/benefits and added value of CVE as a medium of choice.	1. Should I build a CVE for the particular task I have in mind? 2. What are the costs and benefits of building a CVE for this particular task? 3. What factors can influence the project to become a success or a failure?
Usability Design Engineer	Determine the goal of the application; formulate the tasks that the application should support. Translate those given tasks into a design, i.e., a description of a virtual	1. What should a user see in the VE? 2. How can the intended user action sequences be made obvious by the CVE spatial and temporal design?

	environment including all objects and their behaviours.	3. How can different user computer-literacy levels be supported?
Modeller Designer	Translate the design into an actual CVE implementation. Create the visual aspect of the virtual environment and objects.	1. How do I visualise the VE and objects in the VE? 2. How do I make the actions available in the VE visible for the user? 3. How can I work successfully within the limitations of the system underlying the VE?
Developer Programmer	Translate the design into an actual CVE implementation. Combine the visual aspect of an object with the desired behaviour for the given task.	1. What behaviours should be associated with this particular object or space in the VE? 2. How do I create feedback to the user on the effect of the behaviours of the available objects? 3. How do I satisfy the performance constraints associated with distributed, scaleable CVE applications?
Usability Evaluation Engineer	Check user and system requirement specification against the implementation. Perform quality control tests on the implementation of the specifications and requirements.	1. Does the application do what it is supposed to do? 2. Can the users maintain an acceptable level of engagement, i.e. cognitive immersion? 3. Does the VE give the user support in task-flow, i.e. narrative affordances?

Table F.1: Design roles and the relevant questions (adapted from COVEN Del 2.6).

Depending on the size of the team, the goal, the time and the funding available, it is not unusual that one person performs two or more of those roles simultaneously, or that some parts of the design process are skipped or minimised. For example, a ‘coder’ sometimes has the roles of the designer, the modeller and the developer, or a ‘manager’ has the roles of the decision-maker and the designer, or the ‘usability expert’ has the usability design, the designer modeller and/or usability evaluation roles. However, it is recommended to perform those roles very explicitly.

Guideline: work as a multi-disciplinary developers-team.

Guideline: include meetings with representative end-users and external experts.

Design Process

The design process as a whole is governed by trade-off decision making that should satisfy the performance constraint. At the same time the design requirements are driven by the usability demands of the end-users. The only way to allow both driving forces to have an equal impact of the final design is by clarifying the aspects of the design which are directly influenced by trade-off decision making, and by discussing the design options with the complete design team. This team should be minimally comprised of a triangle of designer, programmer, and usability expert. The team should work in such close unison that none of the trade-off design choices are made by one expert only. Once working triangles like these have been established one can start focussing on the actual work of building the CVE: the design process.

Guideline: minimum configuration of design team is a triangle of designer, programmer, and usability expert.

Guideline: the team should work in such close unison that none of the trade-off design choices are made by one expert alone.

Guideline: Perform a requirements analysis at the start of the design process, involving the whole design team to make sure that user and system requirements are properly understood by everyone involved in the design.

Creating the Experience

Every detail of the virtual experience is under control of the designers: the look and feel of the spaces and the virtual embodiments, the location and behaviour of objects in the space, the colours and sounds used, etc. Because the art of creating effective CVEs is still very young, the expressive powers of CVEs as a cognitively immersive medium are still largely unexplored. It is for this reason that the design process should be a carefully structured activity. Traditionally, a requirements analysis is used to structure the design process. Additionally, this method provides techniques for creating 3D structures, and applying narrative affordances as parts of a CVE design process. These issues will be further elaborated upon in the next sections. The following activities are distinguished as part of the design process:

- Structuring the design process rigorously by using requirement analysis techniques;
- Dividing the CVE building task into architectural, semantic, social and temporal issues;
- Creating 3D structures by using the guidelines in this document;
- Applying narrative affordances throughout the CVE and the design process.

In order to design the CVE for usability it is split into several functional layers (see figure F.1). For each layer appropriate design techniques are presented, accompanied with examples, to describe the process through which their respective requirements are clarified. Not all possible features for each layer have been described, rather those features most common to a generic CVE have been clarified where possible. This approach has been adopted in order to illustrate how the use of a systematic methodology can help to clarify the design, and how guidelines can be derived from these clarifications.

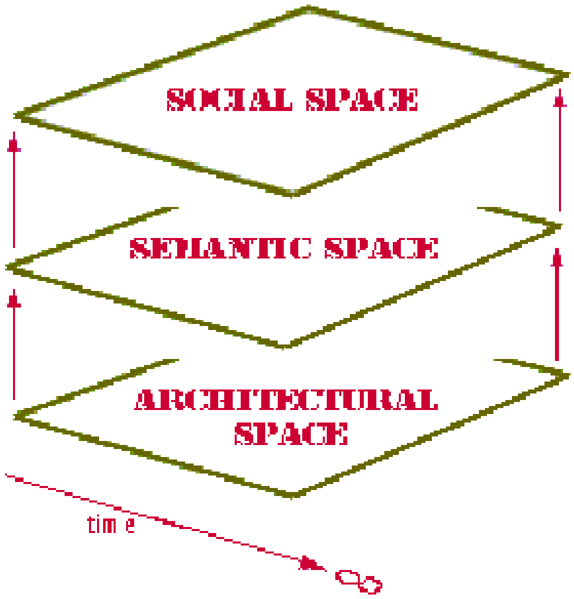

Figure F.1: Three layers of CVE space.

Of first importance is the temporal aspect to the whole CVE experience, which refers to the fact that the CVE is experienced over time, interactions in the CVE are interpreted and reacted to over time, and users learn from their experiences with the CVE over time. The actual flow of the interactions takes place in this time-space continuum and it is important that CVEs support their users in this aspect of the total experience.

Figure F.2: A generic CVE space[1].

The architectural layer of the CVE space model is concerned with the actual layout of the space and adjoining or connected spaces. Secondly, the semantic layer; is concerned with the affordances the spaces, objects and actions in the CVE as they are intended by the designers to be conveyed to the users. Thirdly, the social layer; is concerned with the communications, interactions and collaborations between the users occupying the same CVE, by means of text, audio, visual, and other information cues.

From a CVE users' point of view, these combined layers are how the CVE presents itself to each of them (see figure F.2). Every detail of the virtual experience is under control of the designer: the look and feel of the spaces and the virtual embodiments, the location and behaviour of objects in the space, the colours and sounds used, etc. Because the art of creating effective CVEs is still very young, the expressive powers of CVEs as the cognitively immersive medium it is, are still largely unexplored. It is for this reason that the design process should be a rigorously structured team activity.

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[1] Pictures provided by Dr. Damian Schofield.

The method presented below consists of a number of steps:

- User context analysis
- Task analysis
- User interface design for each interaction layer of the CVE.

F.2 User Context Analysis for CVEs

Part of a standard requirements analysis involves creating a user context analysis. A user context analysis is a necessary element of creating an application, because it helps to clarify the specific user groups, and their respective needs and requirements (Newman and Lamming, 1995). See table F.2 for a generic CVE user context analysis. This user context analysis clarifies CVE user's initial goals with the application, the anticipated user groups, and describes the users, user groups and user tasks.

User Context Analysis	Description
User's initial goals	Collaborate with other CVE participants.
Anticipated User Groups	Novice users, experienced users, game-generation users.
Description of Users	People trying to contact or collaborate on a certain task aiming to satisfy a certain goal mediated by the CVE.
Description of User Groups	Novice users are people who have never used a CVE before.
	Experienced users are people who have used a CVE before, often enough to feel in control of the general interactive tasks and an understanding of the limitations of the medium.
	Game-generation users are people who grew up playing games, expecting interface solutions to the CVE similar to interactive games, internet games, multi-user computer games, etc.
Description of task	Achieve sufficient rapport with the CVE, the other participants in the CVE, and the CVE interface, for satisfactory collaboration.

Table F.2: User context analysis for generic CVE user.

F.3 Task Analysis for CVEs

Instead of defining each task, a number of general task cycles can be defined (derived from Kaur, 1998). These cycles are used when designing the flow of interaction for the objects and the spaces. The cycles dictate what type of task support is necessary for each step of that task. Once the design team has decided what the CVE should be like, what objects should be available and, what specific tasks the CVE should support, then the actual descriptions can be generated by assigning all tasks, objects, spaces, and interactions to one or more interaction cycles. The cycles and their respective definitions and design issues are listed below.

System Initiative Cycle

Definition: Interaction cycle where the user has to deal with the system temporarily taking control over the cause of events in the CVE, either because the user has caused this to happen or because the system has instructions to do so.

Design issues:

I) It needs to be clear to the user that the system has taken control.

II) Allow the user resume control and make the appropriate action clear.

III) Make the effects of system actions visible and recognizable.

IV) Make the system actions interpretable.

V) Make the end of the system action clear.

Normal Task Action Cycle 2D

Definition: Interaction cycle where a user is interacting with 2D information in the environment in order to achieve a certain goal, such as text menu's or 2D pop-up displays.

Design issues:

I) Make it obvious to the users, at the right time, that the action is available.

II) Make the correct action noticeable.

III) Make it obvious what the result of the action will be.

IV) Provide feedback to the users after the action has been taken.

V) Make it obvious what to do next.

Normal Task Action Cycle 3D

Definition: Interaction cycle where a user is interacting with a 3D object in the environment in order to achieve a certain goal

Design issues:

I) The user needs to be enabled to form or remember the task goal from the perceptual affordances in the environment.

II) The user needs to be enabled to specify an intention of what to do from the sequential affordances in the environment.

III) The objects or parts of the environment necessary to carry out the task-action (the user's new intentions) must be clearly visible.

IV) The user must be enabled to locate all objects necessary for the task action.

V) The users must be enabled to approach and orient themselves to the objects so that the intended action can be carried out.

VI) The user must be enabled to decide what action to take and how.

VII) The user must be enabled to carry out the manipulation or action easily.

VIII) It must be made obvious what the consequence of the user's action is.

IX) The user must be able to interpret the change.

X) Make it clear to the user what the next correct/needed action could be.

Goal Directed Exploration Cycle

Definition: Interaction cycle where a user is searching for something known to be in the environment in order to achieve a certain goal.

Design issues:

I) The user needs to know where to start looking.

II) The user needs to be able to determine a pathway towards the search target.

III) The user needs to know how to execute movement and navigation actions.

IV) The user needs to be able to recognise the search target.

V) The user needs to be enabled to approach and orient themselves to the objects so that the necessary action can be carried out.

VI) The user needs to be able to decide what action to take and how.

VII) The user needs to be enabled to carry out the manipulation or action easily.

VIII) The consequence of the users action needs to be visible.

IX) The user needs to be able to interpret the change.

X) It needs to be made clear to the user what the next correct/needed action could be.

Exploratory Browsing Cycle

Definition: Interaction cycle where a user is navigating through the CVE in order to achieve an understanding of the world layout, or world order.

Design issues:

I) The user needs to be able to determine a pathway for movement.

II) The user needs to be able to execute movement and navigation actions.

III) The user needs to be able to recognise objects in the environment.

IV) The user needs to be able to interpret identity, role and behaviours of objects.

V) The user needs to be enabled to remember and recognise important objects or locations.

VI) The user needs to be able to form a mental map of the explored environment.

Collaboration Cycle

Definition: Interaction cycle where the user is interacting with other users in the CVE, either to collaborate on a certain task, or to socialise.

Design Issues:

I) The user needs to be able to locate the other user(s).

II) The user needs to be able to recognise the identity of the other user(s), and tell the other users apart.

III) The communication channels between the users need to be effective.

IV) The actions of the other user(s) need to be visible and recognisable.

V) The user needs to be able to act on a shared object while keeping the other user(s) in view.

VI) The user needs to be able to easily switch views between the shared object, other locations/objects of interest and the other user(s).

VII) The user needs to be able to get an overview of the total shared space and all other users in it.

VIII) The user needs to be able to tell when there are interruptions in the attention of the other user(s) to the CVE.

F.4 User Interface Design for CVEs

Creating the CVE design specification using a systematic approach allows for the design of usable interfaces. The systematic approach described below consists of techniques with which to create specifications of each layer of the CVE space. The layers and their respective techniques are:

- **Temporal Layer:** how to create task-flow with scenarios, storyboards, and sketches.
- **Architectural Layer:** principles of design for 3D structures, principles of design for spaces and paths, principles of design for motion through space.
- **Semantic Layer:** principles of design for representations, principles of design for interaction.
- **Social Layer:** principles of design for virtual embodiments, principles of design for collaboration.

Temporal Space

The temporal aspect that is part of the whole CVE experience, refers to the fact that the CVE is experienced over time. Users learn from their interactions with the CVE, and their expectations and interpretations of the goings on in the CVE space are continuously adjusted based on their experiences. Additionally, interaction itself is a process that takes place over time, and each step in an interaction unfolds itself over time to the users. Interest in time as a component of usability is growing within the HCI community (Fabre and Howard, 1998). Task flow is weakly supported by current CVE interfaces, and how the CVE affects users over time, and how CVE users affect the CVE space and contents is an important aspect contributing to CVE usability.

In order to create a strong flow of interaction, it is advisable to create an interactive narrative for the whole CVE experience. The first steps in satisfying this goal is to create a scenario, a storyboard, and sketches of intended usage of the CVE. With these techniques the design team should be able to derive the kinds of spaces they need to build, the number and style of objects and type of user-actions that need to be supported, and any system functions which need to be created to support users in their interactions.

Scenario

A scenario is a personalised fictional story, with characters, events, products and environments; a written 'premise', as used as the first step in the TV animation writing process. Interaction dialogues can be included in the scenario description, but this is optional. The scenario is written in prose style, and spells out the basic 'story-line' without getting into too much detail. It is commonly two to five pages in length, and is ideally created by the design team as a whole, to ensure a shared vision of the future product. Scenarios can also be used when adding a single new space or function to an existing CVE. In order to create a scenario description the following questions may be used; see table F.3, adapted from Sutcliffe & Kaur, (1998).

I.	Where might the user need to explore?
II.	What information or object might the user need to find?
III.	What operations may the user need to try out?
IV.	What is the next logical action from the user's point of view?

Table F.3: Scenario cycle (adapted from Sutcliffe & Kaur, 1998).

A scenario might look like the following example, which is a small part of a larger scenario description made during the COVEN project:

"Let's meet Max. Max wants to go on vacation but she has not made up her mind where to go. She decides to login on her computer at home that is connected to the Internet. Max searches the World Wide Web for the Travel Operator and takes a look at their site. She enters a Virtual Travel Agency (VTA) which is a three-dimensional computer generated virtual world. Max is represented by her favourite avatar. The VTA is the place where people start when planning a holiday, explore the holiday destination, check out the hotel, the view, the available tourist activities, select their trip and pay for it.

In the VTA travel operators are situated behind counters. Max walks around and speaks to one of these travel operators to obtain information. Than she enters a meeting room populated with other people planning their holiday, represented by avatars, just like Max. After a pleasant chat Max decides to use the teleporting device to check out a virtual impression of few holiday destinations."

This scenario gives an indication of the number and kind of VE spaces that are needed to build this particular application. The spaces, and several requirements derived from their intended usage can be directly formulated. This information is subsequently summarised in one table (see table F.4). By describing the goals of the spaces, the objects needed in them, and the social interaction that these spaces are to support, design requirements are clarified.

Space	Goal	Objects	Social Interaction
Virtual Travel Agency (VTA)	Start of VE. Allow virtual travellers to meet with travel agents and obtain information about various destinations.	Office environment with desks, chairs, a couch, a plant, a clock, posters of holiday destinations.	Create holiday excitement. Allow mingling of travellers.
The Meeting Room	Meeting room for the users who are interested in travelling to a particular holiday destination.	Posters on the wall depicting interesting sites. A slide show of visual and synchronised narrated information. A teleporter to go to virtual holiday destination.	Meet each other, exchange ideas and information. Obtain information about holiday. Visit virtual holiday destination as group or alone.
The teleporter	To give the user the feeling that they are transported somewhere far away from the meeting room.	Console to operate departure as a group or individual.	Providing a group-navigation experience.

Table F.4: Spatial requirements derived from scenario description.

Guideline: Create a scenario description of typical user activity in the future application to develop a sense of the user space.

Guideline: Consider typical user activity, high-demand user activity, and low computer-literacy user activity.

Guideline: Involve the entire team in the creation of the scenario, this will lead to a shared vision of the future product.

Storyboards

Storyboards are sequences of visual images, which focus on the main actions in a possible interaction. The storyboard technique is useful when creating a visual breakdown of crucial interactive or atmospheric elements in the scenario. The storyboard contains key-elements, such as objects or locations, and key user activities belonging to the main task goal of the application. Images can be assembled from magazines, newspapers, clip-art, etc. The main idea is to convey a quick impression of the crucial elements of the application in simple visual manner capturing all significant elements for interaction and atmosphere. The storyboard makes tangible the first ideas and impressions of the designer to the other members of the design team (see Figure F.3 for an example of a simple storyboard).

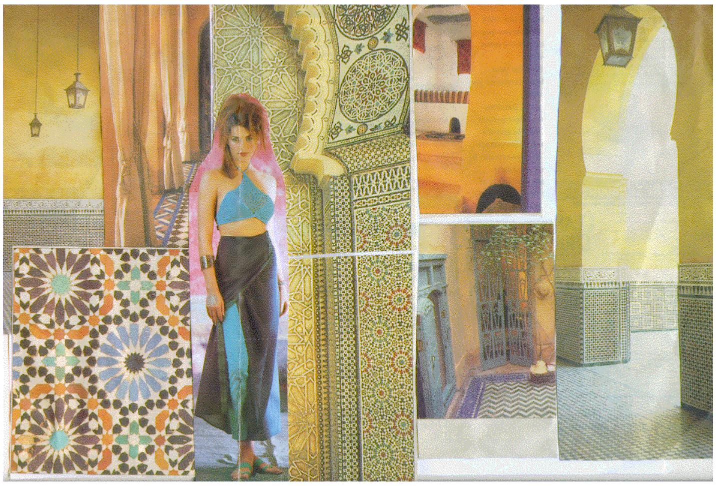

Figure F.3: Storyboard I 'Let's meet Max'.

Sketch

Designers and engineers also make use of sketching to explore and analyse situations, clear up their personal thoughts, and solidify their ideas. It is principally used as the first step toward physical realisation of an abstract idea. Interaction between designers, engineers, and management is enhanced and quickened by the use of pictorial drawings. The basic guidelines for sketching are listed below (see table F.5.):

Steps	**Action**
Step 1	Determine what aspects are to be emphasised and select the best viewpoint.
Step 2	Establish the position of the three major axes, which determine the length, width, and depth of the sketch.
Step 3	Parallel lines must be seen as parallel.
Step 4	Vertical lines in a design should be parallel to the side of the sketching paper.
Step 5	Sketch the basic framework upon which the structure will be built.
Step 6	Include enough information to establish the relative position of other parts.
Step 7	Shading that is skillfully done adds impact to sketches and drawings for presentation.
Step 8	Sketches should have titles; if the sketch is an assembly or an exploded view, the components should have names too.

Table F.5: Basic Guidelines for Sketching (Edel, 1967).

To illustrate the use of a sketch, consider the following drawing (see figure 10.3). In order for the users to navigate through the virtual space effectively, several possible layouts can be explored. Figure F.4 is trying to illustrate how the layout of the room can aid the flow of user action by guiding the view from one moment to the next. First, the user enters the room. Several objects can be seen (the ‘couch’ on the left, the ‘counters’ straight ahead) which typify the use of the room. Immediately after, three obvious exits can be seen. The exit which the designers would like the users to take first, is straight ahead.

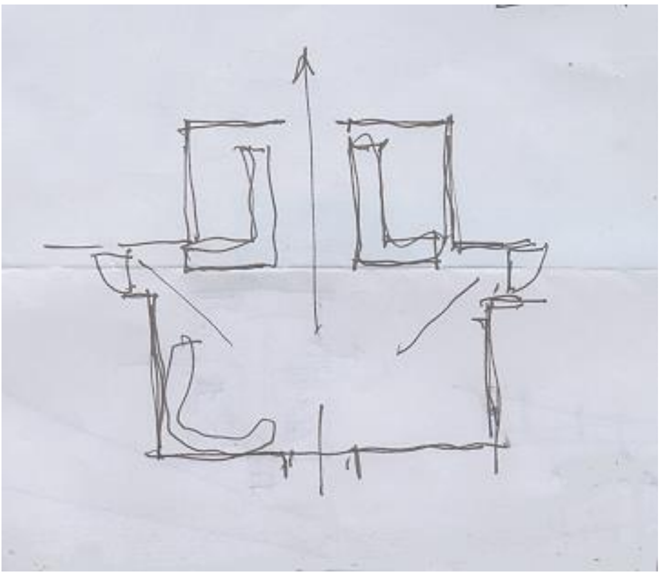

Figure F.4: Layout sketch for the Virtual Travel Agency[2].

Generally, there are seven design principles, which recur in all design, and represent the elements that provide harmonious order to designs (see table F.6).

Design Principle	**Explanation**
Rhythm	A regular occurrence or alternation in design elements.
Dominance	A part that is most easily perceived through some out-standing difference with the rest of the design to attract attention.
Balance	A visual equilibrium in design features that may be either abrupt or gradual.
Transition	A graduation from one feature to another that may be either abrupt or gradual.
Variety	A diversity of difference in design elements in varying degrees.
Contrast	An opposition of design elements in varying degrees.

[2] Picture drawn by Gerrit Priester (Architect HBO BNA).

Unity	A harmonious relationship of all the design elements woven together.

Table F.6: Seven Visual Design Principles (Edel, 1967).

Architectural Space

The architectural space is concerned with the total CVE experience in terms of the lay-out of the spaces (see figure F.5). In designing the spaces it is important to consider the shapes of the spaces in conjunction to each other, the believability of the spaces, and how to design them so that they provide support for communication and collaboration. The design issues under consideration are how humans perceive space, learn the layout, and how spaces are normally built to accommodate for this.

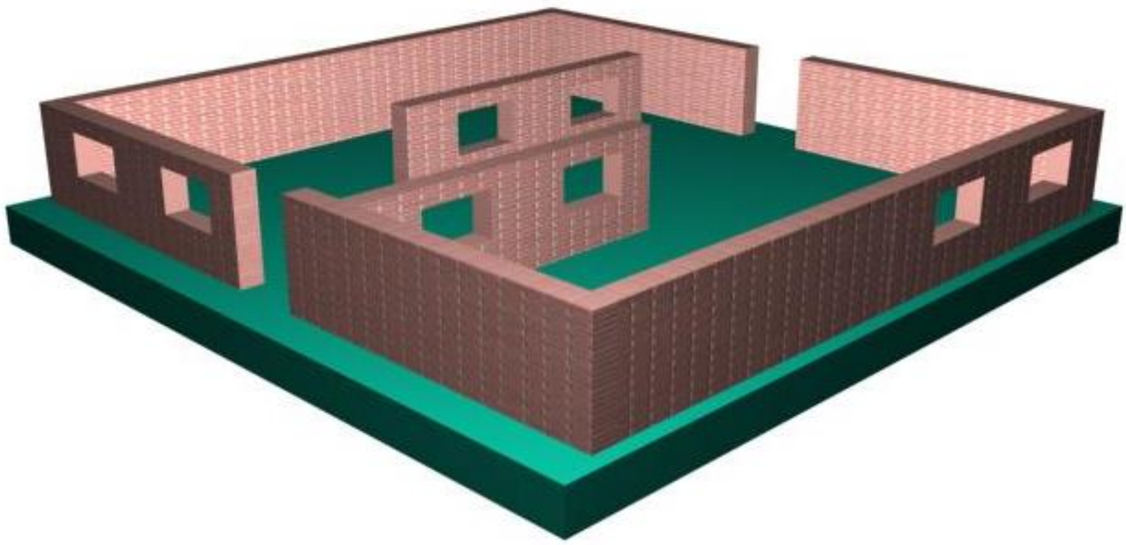

Figure F.5: Architectural layer of CVE space.

The concept of space is closely related to geometry. Our everyday 3D space we are used to, is commonly known as Euclidean space[3]. Mathematically Euclidean space is characterised by orthogonal dimensions, where the number of dimensions is three for the space we live in. Every point in space is defined by coordinates, in an orthogonal coordinate system. The distances between points can be defined, remembered and explained to others. VE space is not entirely Euclidean. In fact, VE space is only Euclidean if it has been made so. Usually, VE spaces are Euclidean sub-spaces, interconnected by teleportation portals. But even those Euclidean sub-spaces can show peculiarities not found in everyday real spaces. Most notably:

- Primal entry into the VE; the user embodiment appears out of nowhere.
- One door connecting to different places for different users depending on their privileges or preferences.
- Exit in room A leads to room B, but not vice versa.
- Two or more spaces can be adjacent to the same side of another space, theoretically – but not practically – overlapping onto the same grid-space.
- Inside dimensions can be larger or smaller than would be coherent with the suggested size of the outside dimensions of that space.
- Nested spaces, where the entry and/or exit to a much larger space is inside a much smaller space.

Human spatial behaviour is dependent on the individual's mental representation of the spatial environment. This representation is used to direct action and the experiences

[3] The Euclidean space concept is no longer consistent with temporary knowledge from Physics. Space is no longer seen as a 3 dimensional concept, but instead as a four-dimensional space-time continuum, still Euclidean space in an adequate concept for most everyday phenomena.

are used to further modify the representation; creating a mental map of the traversed space (Downs & Stea, 1975).

Building CVE spaces that seemingly enact everyday Euclidean space as closely as possible, seems mandatory if we want to support users in building a mental map of CVE. Deviations from Euclidean spatial layout could be confusing to the user, so these should be enacted to the user as obviously as possible, adding to their understanding of the CVE layout. Generally, there are three aspects which need special attention when designing architectural space:

- The 3D structures.
- The path through the 3D structures.
- The motion along the paths.

The elements which create the illusion of space and motion, are the spaces themselves, the objects, motion of the virtual embodiment of self, others, and of objects.

Creating 3D Structures for Usability

Architects and city-planners have refined our knowledge on how to support humans in their navigation, understanding and use of everyday space. Besides the ready available principles of architecture, there are a lot of spatial infrastructure constructs, which support people in their interaction with the world and each other. These principles and constructs can be adapted and reused in building CVEs.

According to Unwin (1997) the root definition of architecture is considered to be its conceptual organisation, its intellectual structure:

> *"The generative core of architecture is the identification of place. Significantly, architecture relates directly to the things we do; it changes and evolves as new, or reinterpreted, ways of identifying places are invented or refined. In any example there will be places proposed by the designer and places created by the users (these may or may not match). Everyone of the places [..] is perceived in terms of how it relates to use, occupation, meaning. People and their activities are an indispensable component of architecture, not merely as spectators to be entertained, but as contributors and participants."*

The visual field can also interpreted as a space, a void within which the user can move. The basic sensation of space is confinement to a certain degree. This sensation is modified by in many ways, such as the form, size, and proportions of the space, the kinds of objects in it, and the position of the user in the space. It is also modified by the speed at which one is travelling; things moving by fast become blurred. Spatial contrast also makes a strong visual impact, and the sequence of spatial changes can be a thrilling experience. In order to create a convincing space certain criteria need to be satisfied. These criteria have been defined by Appleyard, Lynch, and Myer (1964), and they are listed below:

a) *The quality of the enclosure;* which is based on the presence and position of enclosing objects or surfaces, their solidity and degree of enclosure.

b) The proportions of the enclosure; which are based on scale with respect to the observer, and the position of the observer.

c) *The qualities of the light;* which make the space apparent; based on light intensity and direction.

d) The relationship of spaces in sequence; which is influenced by jointing and overlapping of spaces.

e) The direction of principal views; which draw the eye toward different aspects of the spatial enclosure.

The more of these criteria are satisfied, the more likely it is that the illusion of space and motion is called forth, and the more likely it is that the illusion will remain fixed in the mind of the user. It may not always be feasible or necessary to satisfy all these criteria. In that case it needs to be established which criteria are there by force of the environment as it is, and which criteria can be satisfied by adding a few more spatial characteristics. Using the above list of criteria is a good way of finding minimal additions to the CVE design, which will have a maximum effect on increasing the effectiveness of the illusion. The general building blocks of architectural structures can used for CVE design, and they are listed below (see table F.7).

Architectural Element	**Explanation**
Defined area of ground	Small or large, regular or irregular in shape, precise boundaries or edges blending into surroundings.
Raised area or platform	High or low, large, medium sized or small.
Lowered area or pit	Place below natural level of ground.
Marker	Identifying a particular place. Occupying a particular spot, standing out from the surroundings.
Focus	Element upon which concentration or attention is directly brought to bear.
Barrier	Dividing one place from another. Barriers combined from an enclosure. Walls.
Roof, or canopy	Dividing a place from the sky, defining an area of ground beneath it, small, or big. Walls and roof create a space separated from everywhere else.
Supporting posts or columns	Support for roof, small or large.
Path	A place along which one moves, straight or irregular, inclined, formally laid out or defined by use.
Openings	Doorways through which one passes from one space to another, windows through which one can look and which allow passage of light and air.
Bridge	A path over a barrier, a platform, or a roof.
Modifying elements	The basic elements of architecture when used together introduce various additional factors, the modifying elements. These modifying elements also help in the identification of place.
Light	Both natural and artificial light can be manipulated by design to identify particular places and give places a particular character. Light can be related to the activity in a place. A spotlight can identify a particular spot. Beams of light can draw attention to their source.
Colour	Colour together with light can play a part in identifying a place. Colour is not just a matter of decoration, or the creation of particular moods, it also plays a part in recognition. Colour is also used in coding. A coloured line, or a change in colour might indicate a path or help people find their way.
Sound	Places can be distinguished by the sounds they make, or by the ways in which

	they affect sounds made in them.
Texture	Texture contributes to the identification of place.
Scale	Scale is about relative sizes. It refers to the size of something relative to oneself. The experience of a place is affected by its scale.
Time	It takes time to experience a building through discovery; outward appearance, approach, entrance, exploration of the interior spaces, etc. Buildings evolve over time, both due to deterioration and altered use.

Table F.7: General Building Blocks of Architecture.

Creating Paths Through 3D Structures

In applications where exploration is important, exploration areas of interest, and paths should be specified. An exploration path through the CVE can be specified which represents a typical pattern of exploration implied by the users information needs. An overall floor plan of the virtual world should be created and the exploration plan traced in it to assess how much it is (a) necessary to explore and (b) likely to be explored in view of the cues given in the environment (Sutcliffe and Kaur, 1998).

The way in which people organise their spaces is related to their beliefs, their aspirations, their world view, and the human size and capacities. Kevin Lynch (1960) looked at how people build their mental representations of the city they live in. Lynch isolated five distinct elements in the mental representations, which he calls the 'environmental image'. These elements and a short explanation are provided below (see table F.8).

Element	**What it does**
Paths	Paths are the most dominant feature in the image of an environment. Paths are routes connecting locations, and usually the first features learned in an unknown environment. Paths commonly show directionality. A path is by definition a trajectory travelled to

	'reach a certain point'. Often paths show directionality as a 'gradient' in terms of distinguishing features along the path, cumulative into one direction. These gradients allow people to estimate their location and progress. Paths are seldom straight lines. A crossing of paths forms a node. Path intersections are always points of decision, so that it is important to visually support the decision and not break the path or the gradient in the path.
Edges	The distinction between a path and edge depends on the perspective of the observer. Edges can be crossable or uncrossable. In the latter case the edge becomes a real border. Edges, like paths sometimes have clear directional qualities. Edges often are real borders in the environment.
Districts	Districts are areas consisting of several other elements in combination. The elements are grouped by functional concentration. Districts can include other smaller districts. Districts can have clear boundaries consisting of a path or edge, but they can also have more fuzzy ones which just show a slow change in character.
Nodes	A node is a small area, focus point which can be entered. They are conceptually small but important points since they occur at intersections. The observer heightens her attention at nodes and those places and nearby elements are perceived more intensely because a decision about direction has to be made. Nodes can be introvert or extrovert. Introverted places give the observer the feeling of being inside of the place. Extrovert places additionally provide a feeling for directionality.
Landmarks	Landmarks are elements showing an unmistakable form. It is distinguishable from all other instances of similar objects in the environment. Landmarks are of special importance when giving directions to people since they are easily recognisable and can give the traveller a feeling of progress. Landmarks are easy to remember when they are prominent against the background, have a clear form and are in a prominent location.

Table F.8: The five elements of the environmental image used in navigation (Lynch, 1960).

Creating the Illusion of Motion Through Space

The criteria for the perception of motion and (Appleyard, Lynch, & Myer, 1964) can be used to define the determinants a virtual space should possess to qualify as a realistic motion.

1) Apparent self motion

This will be suggested by creating the impression of speed and direction, and by their changes, such as stop-go, accelerate-decelerate, up-down, right-left. Many metaphors can be used to create the illusion of direction; a very large one is the city metaphor (Dieberger and Tromp, 1993).

The visual judgement of motion is based on motion parallax; when moving one's head from side to side the objects one sees are displaced at different rates. Motion is than calculated by the brain from the apparent motion of the exterior objects and is interpreted as being motion in relation to the enclosing spatial form.

2) Apparent motion of the visual field:

This will be suggested by creating the impression of passing along-side, overhead, or underneath; rotation, translation; spreading or shrinking of outline or texture; general stability or instability; apparent velocity or lack of it. Even in text-based environments the illusion of motion is easily created, because the user can move freely through the VE (Tromp and Dieberger, 1993).

Users of most of the state of the art CVEs of today will have no real bodily sensations of movement. True kinaesthetic sensations are thus largely absent, therefore, the user depends on vision to give her a sense of motion. Apparent motion of the surrounding objects, which the user knows to be really fixed, are generally interpreted as the result of her own progression. Where surrounding objects are far off, or few, or featureless, or moving with the user, then the sensation is one of floating, of no forward movement.

> Conversely, where the near environment has many highly articulated objects, the sensation may be one of great velocity. Details close at hand, such as textures on the wall, rhythm of lights, patterns underneath, all reinforce the sense of speed, according to their frequency and closeness. Apparent speed is also heightened on the downgrade, or on sharp turns, while tempo seems to slacken when going upward. The sense of varied motion is inherently enjoyable if continuous, and not too violent.

In principle the design team can predict the most likely path taken through the CVE by a typical user, and the design team should endeavour to design the lay-out of the rooms and objects so that navigation and recognition are as easy as possible. Providing users with a map of the total space, and automatic movement along paths or to specified places, objects, or users seems mandatory.

Guideline: The lay-out of the space can guide users from one action to the next.

Guideline: Support users in their way finding by providing landmarks.

Guideline: Suggest social usage for the space by including typical features and objects.

Guideline: Spatial organisation will help users find things and focus on their task.

Guideline: Distant ground, middle ground, and foreground, provide levels of task supporting context.

Semantic Space

The semantic space refers to the total CVE experience, in terms of how it signifies usage to the user. It is concerned with effective 3D interactivity in the CVE and with the CVE objects. The aim is to create intuitively understood representations and interactions in CVEs.

Figure F.6: Semantic layer of CVE space.

Semantics is the study of meanings; the study of what and how things in our environment relate to us; what they signify to us. Semantics has a long history in the philosophy of language and in formal and mathematical logic. There are two aspects of the semantics of CVE spaces and objects, directly relevant to the design of usability for CVEs:

- Representational issues.
- Interactional issues.

Instead of making arbitrary choices in the simplification of representation, the design ought to be simplified by amplifying the salient interactive features of spaces and objects. Credibility of the happenings in the CVE is not based on realism as compared to the real world, but on realism within the frame of reference of the happening. Things do not have to be real but they have to be realistic to be credible. This means we can use metaphors and magic features for CVEs as well as realistic representations. Metaphors are used as a way of making unknown things more quickly understood by representing them as something already known (i.e. a paintpot icon to signify the action of filling shapes with colour). Magic features are a special instance of metaphors where something unknown (i.e. teleportation) with something from the collective human fantasy stories (i.e. a magic carpet to teleport with). The main important issue is to create a clear flow of interaction. Interactions are sequences actions. These sequences should lead the user intuitively from one logical action to the next.

Representational Issues

One of the most important characteristics of human cognition and perception, is our ability and need to store mental representations of our experiences of the world, the objects, entities and events, in our memory (or more precisely semantic memory) in terms of conceptual categories. The role of the human category system is to reflect perceived world structure in a set of categories, which provide maximum information with minimum retrieval effort (Roth and Frisby, 1986). Spaces, objects, entities and events which are clearly recognisable as belonging to a certain category are easily recognised and their functionality is quickly grasped. Thus, certain items we encounter are judged more typical of a conceptual category than others, and research has shown that the recognition time for these items is the lowest (see. for instance Roth and Frisby (1986), for a more detailed discussion of these issues).

Conceptual knowledge can be broken down into three broad aspects. These three aspects of conceptual knowledge are the spatial phenomenon of the concept, locational information and attributional information (see figure F.7. for an illustration of the structure of conceptual knowledge for a typical 'post-office').

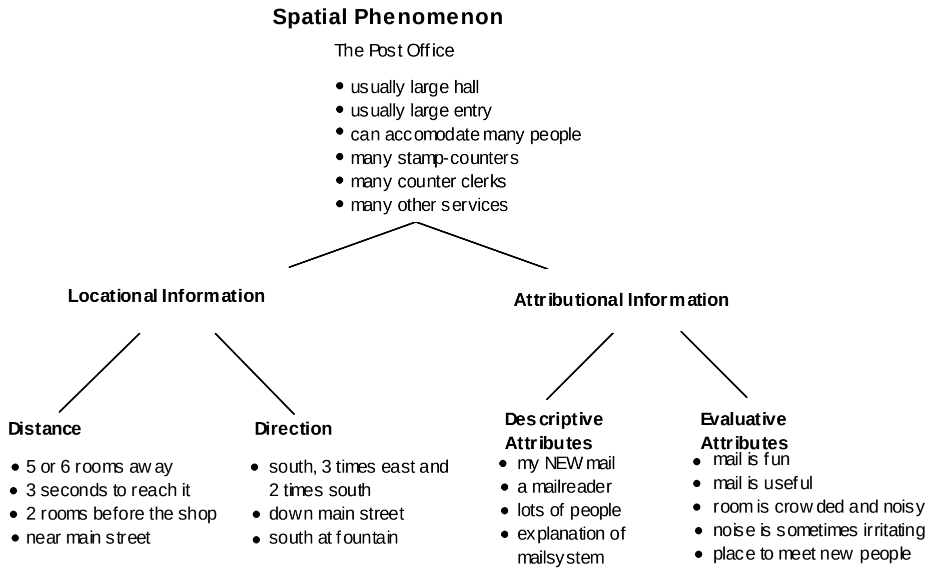

Figure F.7: The Conceptual knowledge framework, illustrated with the example of a CVE post-office.

The spatial phenomenon contains knowledge of the general function of the concept, which is in this case a post-office. Locational information associated with the concept post-office, is general knowledge about where the post-office usually can be found, and how to get there, etc. Attributional information, is general opinions about the spatial phenomenon, such as in the case of the post-office example, when the busy times are, and when it closes. These three aspects of conceptual knowledge are discussed in more detail below.

Spatial Phenomenon

The concept post-office is a spatial phenomenon, it occupies a place in the CVE, and users understand without much explanation how to use it, and where to find it, because they can associate their conceptual knowledge of a real post office with the virtual one. A concept has all kinds of conceptual information attached to it, such as what a typical representation of that concept is - in this case the typical conceptual knowledge associated with a post-office; one can go there to deal with mail, it usually offers a range of services, and other people are likely to be there dealing with their mail too.

Locational Information

A spatial phenomenon has typical information associated with it such as where it is located, what it looks like, and how good or bad it is. Locational information consists of information about the distance of the spatial phenomenon to other phenomena in the CVE, and information on how to get there from somewhere else. Users typically learn about distance and direction by counting the number of times they have to go in a certain direction to reach their goal. They might learn these numbers by looking around and paying close attention to their surroundings for some time, or by memorizing obvious landmarks, the number of turns and rooms to take in certain directions, or by asking an other participant.

1) *Distance*

A user may remember that the post-office is 5 or 6 rooms away, that it takes about 3 seconds to reach it, that it is 2 rooms before the shop, so finding oneself at the shop means having overshot the post-office, and that it is near the main street, so seeing the main street is feedback that to the user that she is still on the right track.

2) *Direction*

In terms of direction a user may remember that it is one time south, 3 times east, and than 2 times south, that it is down main street, and that one has to go south at the fountain - a very obvious landmark.

Attributional Information

The salience of descriptive attributes contributes to navigation. If a participant has memorized many objects or other obvious landmarks in a room, it should be easier for her to recall where she is, and where she should go from there to reach her destination. Unique features of a room are the source of a rich set of distinctive landmarks, which in turn, increase the number of retrieval cues. Locations often take on significance. For instance, one might remember that in the room with the checked floor pattern, one had to turn left because that is where you met another user who had got lost last time you where there. These evaluative attributes should also increase the number of retrieval cues.

1) *Descriptive*

In terms of descriptive attributional information a user may associated with the post-office, and thus be able to remember this function and where to find it fairly quickly, is that it offer the user her new mail, a mail-reader to read the mail, lots of people she might want to meet or avoid, and an explanation of the mail system in case she needs to look something up.

2) *Evaluative*

Evaluative attributional information is a very powerful feature which can help users to remember where they have been, and what the function of the place or object was. In the case of the post-office, users may associated the information that mail is fun to receive, mail is a useful function, the room is crowded and noisy, that the noise is sometimes irritating when trying to write or think, but that it is also a good place to meet new people.

When creating the virtual meeting room for the COVEN Platform, a choice had to be made as to which functionality to implement and which could be left to a later time. The space and objects still had to look convincing and intuitive. For this reason listing all elements which could be implemented allowed us to decide which ones where the most relevant for us to reach our goal (see table F.9).

Conceptual Knowledge Elements	**Associated Information**	**Description**	**Implement**
Spatial Phenomenon	The Virtual Travellers Meeting Room	Meeting room for the users who are interested in travelling to a particular holiday destination.	Yes
Locational Information	In the travel agency	Directly adjacent.	Yes
Distance	Very nearby	Through one door.	Yes

Direction	Straight through the virtual travel agency room, through connecting door.	Door from virtual travel agency to the virtual travellers meeting room.	Yes
Attributional Information	Meeting place, information about holiday destination	Meet each other, exchange ideas and information. Obtain information about holiday. Visit virtual holiday destination as group or alone.	No Yes Yes
Descriptive Attributes	Possible large amounts of customers. Large amounts of travel information	Posters on the wall depicting interesting sites. A slide show of visual and synchronised narrated information. A teleporter to go to virtual holiday destination.	Yes Yes Yes
Evaluative Attributes	Useful information from other travellers. Potential holiday friends. Place to share holiday experiences.	Bulletin Boards to post questions and answers. Groups of interests which one can join.	No No

Table F.9: Conceptual knowledge associated with travel agency meeting room.

In order to create easy to use spaces and objects, the design ought to be simplified by amplifying the salient interactive features. Spaces and objects can be build carefully by using the above list of elements of conceptual knowledge. The whole design team should be involved in clarifying all the elements which are commonly known to be associated with the kind of space or object one wants to design. Once the list has been exhaustively answered, one can decide to pick only the most salient and most important elements.

Guideline: amplify functionality by simplifying the representations.

Guideline: find the minimum number of conceptual elements needed to convey the available function of spaces and objects.

Guideline: control the effort invested in each iteration of the design by determining the number of conceptual elements needed balanced against the technical complexity to create it.

Guideline: Use contextualisation by providing a visual framework for the data, to make it easier to interpret.

Interactional Issues

Perceptual affordances, sequential affordances, narrative affordances for CVE interaction can be designed using six task interaction cycles (Kaur et. al., 1997; D 3.6C, 1998). To use the cycles in the design specification, each task is assigned to the appropriate interaction cycle(s), see table F.10.

Class of Function	Sub-Function	Description	Indicate Cycles
TurnTaking Tool	Speaker	Perform speaker continuation gestures	**System Initiative Cycle** **Collaboration Cycle**
	Listener	Perform active listener gestures	**System Initiative Cycle** **Collaboration Cycle**
	Next-Speaker	Initiate wish to take next-turn gestures	**Normal task action Cycle 2D**
Absence	Command	Initiate nodding-off body-stance	**Normal task action Cycle 2D**
	Automatic	Initiate nodding-off body-stance and start 'snoring' noise after x minutes idle time	**System Initiative Cycle**

Privatized Group Audio	Within group	Members of each group have a private audio channel to each other (walkie-talkie style)	**Normal task action Cycle 3D**
	Within room	Only participants in the same room can hear each other.	**System Initiative Cycle**
	Whisper?	Users can initiate a private audio channel with one other user.	**Normal task action Cycle 3D**

Table F.10: Example Interaction Cycle Analysis

Subsequently the design team needs to specify how the design is going to look for each atomic task belonging to each interaction cycle. It is up to the design team as a whole to come up with sufficient interaction support for the user. However, these lists of questions which must be satisfied should help the team as a whole to focus on the important aspects for the flow of interaction, which contributes to the ultimate usability of the CVE.

Flow of interaction needs to be supported for each space, object and other kind of user activity in the CVE. Using the interaction cycles, the design can be specified on precisely on this level; the level of narrative affordance. The design should be specified by the design team as a whole. It is recommended to include a number of representative end-user in the team during this meeting specifically.

Guideline: Use selective emphasis by highlighting the interactive features and suppressing non-interactive features, to reveal patterns of functionality.

Guideline: Use transformation by changing the representation in order to make interpretation easier.

Guideline: Create objects and spaces, which look and behave like their real world counterparts, whenever possible.

Guideline: Employ realism to aid recognition and understanding of the object or space.

Guideline: Emphasise functionality with a combination of visuals, interactions, and sounds.

Guideline: Preserve real world proportions and relationships.

Social Space

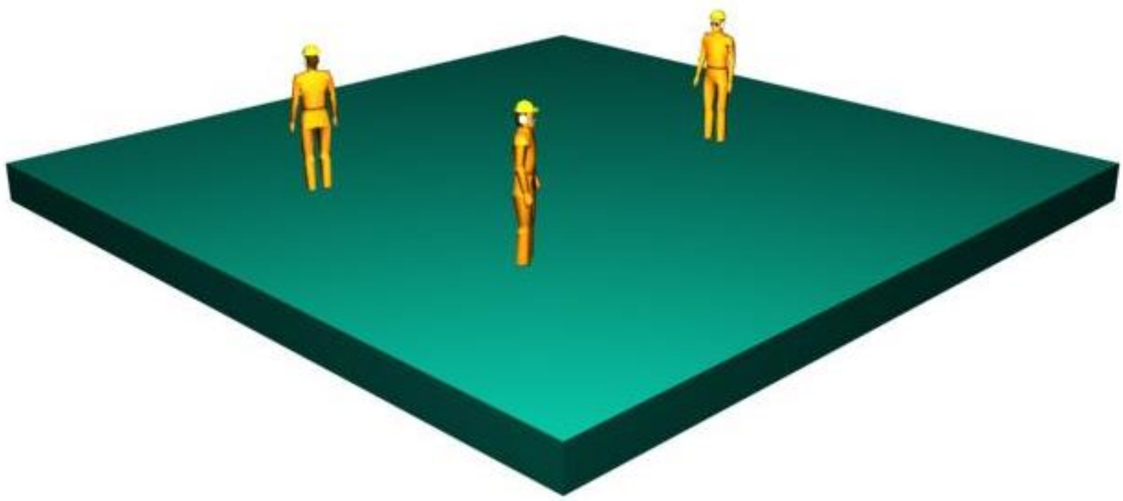

Figure F.8: Social layer of CVE space.

The social space is concerned with the total CVE experience in terms of how it allows users to be aware of the other users' and their activities, to find each other, what means there are for the users to introduce themselves and remember each other, and how they are enabled to communicate and collaborate (see figure F.8).

For user interaction and collaboration to work effectively CVE users need to be aware of their own embodiments, the other participants' embodiments, and the surrounding spaces and objects (see table F.11). This awareness allows them to interpret the behaviours of others, and to anticipate their next actions. Awareness is constantly in flux. They pay attention to one thing and then to another. Sometimes they pay attention to one thing at the exclusion of others things, and sometimes they do more than one thing at the time. Through this awareness users attain an understanding of the goings on in the CVE, they learn from their interactions with others participants, with the CVE, and with the objects in it, about their embodiment, its limitations, the available repertoire of movements and expressions, and what to expect from a CVE interaction.

Elements of Social Space	**Definitions**	**Importances**
Virtual Body Representation	The users' virtual embodiment (VB), or Placemarker and Direct Manipulation Device	The VB indicates location of the owner to the owner and to the other participants in the CVE space. The VB is the 'user interface' to the VE space, the objects and for collaboration.
Surrounding Space	Everything that is not part of the owners' VB, including objects.	The position of the VB in the space indicates something about the owners' activities in the CVE to the other participants. Spaces suggest 'appropriate' social acts. Object affordances suggest 'appropriate' usage, which can be essential elements in performing

		meaningful social acts in a CVE.

Table F.11: The elements of social space.

Virtual Embodiment

The virtual body representation can, in theory, have almost any shape or form. It is the interaction device inside the virtual world, and the user has to be able to identify with the VB to the point where it becomes an extension of themselves. The virtual body representation has to become an extension of ones normal body in order to effectively interact with the VE and to learn from these interactions. It will be easier to interact when the VB behaves in an equal way to the real body.

Guideline: Users learn to identify with their virtual body and the virtual space by interacting in the CVE, provided the CVE sends consistent and continues feedback to the user about the results of action performed.

CVE Mediated Human-Human Interaction

In CVEs, participants are only aware of each other's voices and virtual embodiments, and the verbal and co-verbal cues that can be observed from these. Co-verbal cues are expressions of body and facial position, the relation of the position of one person to other persons, the environment and objects, changes in the positions in relation to things going in the environment, and some para-language utterances, such as "Uhuh", "Aha", "Hmm". These co-verbal behaviours are here listed alongside the importance of their existence during interaction (see table F.12). These co-verbal behaviours have been observed to make a great impact on social interactions in the real world, and they are largely unsupported in the CVEs of today, leading to difficulties in interpretation of the meaning of actions of others, and misunderstandings in conversation and collaboration.

Co-Verbal Social Acts	**Definitions**	**Importances**
Phatic Communication	The exchange of stereotyped phrases and commonplace remarks to establish and maintain a feeling of social solidarity and well-being	During three major phases of the interaction: the opening phase, the middle phase, and the closing phase
Spatial Regulation	The arrangement of single or combined average body-size related spaces around and between people and objects, signifying temporary or permanent micro-territories	Governs the judgement about the appropriateness and our competence at navigation and positioning of ourselves in shared spaces
Proxemic Shifts	Patterns of interpersonal distance in face-to-face encounters	Accompanies and influences changes in the topic or in the social relationship between speakers (i.e. situational shifts)
Co-Verbal Behaviour	Non-verbal communication accompanying verbal communication	The understanding of social interaction. The most fruitful co-verbal behaviours for understanding and observing social interaction are head nodding, face looking, smiling, head touching, and speaking, including simultaneous speech
Turn-Taking in Conversation	An auditor may claim the turn when the current speaker displays a turn-signal. A turn-signal is composed of a set of six behavioural cues, found variously in intonation, context, syntax, paralanguage, and body-motion	Taking turns in a conversation and the alternation of action and inaction, and the subsequent rotation of performance among individuals in a group is the most salient feature of group dynamics

Table F.12: Co-verbal behaviours common to real world interaction.

The interpretation and display of proxemic shifts, and the observation of the spatial regulation rules are influenced by the ability to fine-tune navigation and positioning of ones virtual embodiment. Conversation, turn taking, and the display and perception of co-verbal cues are influenced by the performance and reliability of the audio-channel. And finally, the success of the collaboration is heavily influenced by the success of the phatic communication, which in its turn is dependent on the performance and perceived reliability of the audio-channel and the participants' ability to coordinate their embodiments.

Guideline: Create automatic co-verbal behaviours where possible.

Guideline: Create support for displaying and perceiving co-verbal behaviours.

Focussed and Unfocussed Collaboration

The relevant findings for virtual collaborative work can be summarised in table F.13.

Collaborative Social Acts	Definitions	Importances for CVEs
Continuous Transition	Co-operative work involves a continuous transition between multiple, interrelated individual and collaborative tasks.	Switch smoothly between individual and collaborative tasks
Peripheral Awareness	An individual's ability to work on collaborative tasks relies upon peripheral awareness and monitoring of other participants' work.	The embodiment should enable the user to be aware of others and their work, in the environment
Activity mediated	The participants' activities are mediated and rendered visible through shared objects and artefacts.	Preferably, shared artefacts should be visible and available in the shared CVE space.
Focussed and Unfocussed	Both focused and unfocussed	The embodiment should make

Collaboration	collaboration is largely accomplished through alignment towards the focal area of the shared activity, such as a shared document.	clear where the user has focused his/her attention
Adjusting access to others activities	Collaborative work relies upon individuals subtly and continuously adjusting their access to each others' activities.	The embodiments should convey a sense of the current activities of its owner

Table F.13: Summary of support for CVE collaboration.

Guideline: The CVE should allow for switching from unfocussed to focussed collaboration, which depends on the peripheral awareness of one participant of the other participants and their activities.

Meta-Collaboration

Participants in a CVE have to establish and maintain a set of social norms or etiquette of social conduct during the interaction, they have to be able to either hear or see each other, they have to be reasonably competent at navigation, they have to be relatively undistracted by concerns of audibility, visibility, and sociability and, they have to be certain that they are audible and visible to the other participants when they think they are and vice versa. Participants have to rapidly adapt their expectations to the limitations of the CVE situation. It is difficult - especially for novice participants - to judge which particular aspects of the CVE interactions can or must be attributed to limitations of the technology, and which to a participant.

Example Scenario

Automatic behaviours to initiate phatic communication and signal turn-taking are a sequence of automatic actions which start the moment a participant enters the VE. The avatar automatically searches for the optimal place in the VE space where the participant will have the best view of the other participants. If this automatic sequence is uninterrupted by the participant the avatar will start waving automatically, go up to the nearest other active avatar and smile, when still uninterrupted it could go to the next nearest other avatar, etc. Once a participant is a member of a group this automatic behaviour will be restricted to group members only.

Requirements Specification

In order to facilitate the turn-taking a speaker will make automatic speaker gestures, a listener will make automatic listener gestures and a potential next-speaker will give automatic turn-taking signals. Users can create their own sets of behaviours for these automatic sequences of gestures.

- Speaker: A speaker will automatically raise and lower her arms and smile while speaking.

- Listener: A listener will automatically nod in the direction of the speaker while listening.

- Next-Speaker: A would-be next-speaker will cough and raise a hand. The user can press a button to initiate this behaviour.

- Absence: When a user has to switch attention away from the VE they can make the head of their Avatar slump. After x amount of idle time the Avatar will make very soft snoring noises.

- Privatised Group Audio: Users are able to select group audio, and proceed to discuss privately with other members of the group.

F.5 Conclusions

CVEs have to be developed in a systematic way, in order to capture the design requirements for the support of task-flow. The techniques presented here are a selection of a large set of usability engineering techniques. They have been chosen for their appropriateness to the design of CVEs. The effectiveness of the CVE design method presented here has not yet been tested.